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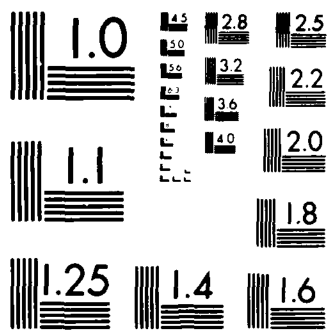

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ECONOMIC FEASIBILITY OF FUEL CELL
ENERGY SYSTEMS FOR SELECTED FACILITIES
ON WRIGHT-PATTERSON AFB, OHIO

THESIS

Stephen A. Bird
Captain, USAF

AFIT/GEM/LSM/86S-2

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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AFIT/GEM/LSM/86S-2

ECONOMIC FEASIBILITY OF FUEL CELL ENERGY SYSTEMS FOR SELECTED FACILITIES ON WRIGHT-PATTERSON AIR FORCE BASE, OHIO

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Engineering Management

Stephen A. Bird, B. S.

Captain, USAF

September 1986

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Abstract

This thesis developed life-cycle costs of retrofitting fuel cell powered energy systems into existing facilities on Wright-Patterson Air Force Base (WPAFB), Ohio. These life-cycle costs were compared with existing costs for providing facility energy via commercially supplied electricity and natural gas and/or base generated steam. Three facilities representative of the main facility types on WPAFB were examined: Military Family Housing (MFH) units, an office/classroom building, and an office/lab building. An analysis of the cost comparisons was performed to determine if fuel cell energy systems can be economically competitive with existing facility energy utilization systems. The results of this analysis are contained in Chapter IV.

ECONOMIC FEASIBILITY OF FUEL CELL ENERGY SYSTEMS FOR SELECTED FACILITIES ON WRIGHT-PATTERSON AIR FORCE BASE, OHIO

I. Introduction

Background

Presidential and Congressional directives concerning energy usage by the Air Force are translated into policy by the Air Force Energy Plan. This plan is developed annually to assist Air Force installations and activities in the preparation and implementation of their energy programs. Three of the facility energy goals set by the plan and of particular significance to this study are: first, the installation of least life-cycle cost energy conservation retrofits in buildings; second, the use of advanced energy technology to provide facility energy; and third, the reduction of the use of petroleum-based fuels [7:2].

An energy system that has the potential to help achieve all three of these goals is based on a device called a fuel cell. A fuel cell can be thought of as a type of battery in that a direct current flows when the positive and negative terminals are connected. However, unlike a battery that must be recharged from a source of electrical energy (a generator), a fuel cell converts chemical energy into electrical and heat energy by means of a chemical reaction between hydrogen (the fuel) and oxygen. Thus, a fuel cell

can generate electricity with the continuous input of hydrogen and oxygen gas without the need for periodic recharging [2:2].

The Department of Energy (DOE) and the Air Force have already studied several market areas where fuel cell energy systems would be economically competitive with conventional facility energy systems which usually rely on purchased electricity and heating oil. In general, the study found that on a national basis, on-site fuel cell power systems could reduce the energy resource requirements for commercial buildings by 30 percent [2:6]. An energy system that the Air Force believes can significantly reduce consumption of energy resources is certainly worthy of further investigation.

Problem Statement

Recent studies of fuel cell energy systems have shown that installation of these energy systems in certain types of facilities is economically feasible [2:75]. The purpose of this study is to determine the economic feasibility of installing such systems at WPAFB. This study is divided into two main parts. The first part identifies the advantageous features of a fuel cell energy system, such as high relative efficiency and low noise and exhaust emissions. By optimally matching these features to specific facilities at WPAFB, the energy saving potential

can be maximized. The second part of this study is an economic analysis of the installation and operating costs of a fuel cell system at the facilities chosen.

Investigative Questions

A certain amount of background was needed to explain the basic operation and advantages of a fuel cell energy system. This and other information was obtained by means of research of applicable documents and evaluation of data collected to provide answers to the following list of questions:

-What are the current DOE and Air Force policies regarding the potential use of fuel cell energy systems?

-What are the advantages of a fuel cell energy system when compared to conventional energy systems?

-How does a fuel cell operate?

-What are the results of recent feasibility studies?

-Would certain facilities at WPAFB benefit in terms of energy cost reduction from the installation of a fuel cell energy system?

Scope and Limitations

This thesis states the current DOE and Air Force policies regarding fuel cell systems; states the advantages of such a system over conventional energy systems; describes the operation of a fuel cell energy system; describes recent feasibility studies; provides a cost estimate for the

retrofit of a fuel cell system into certain existing facilities at WPAFB, OH; and presents a life cycle cost analysis that determines if a fuel cell system installation would be cost effective.

Computer program models have been used in a number of fuel cell feasibility studies to simulate the operation of various system configurations in a wide range of facility types (e.g.,office buildings, hospitals, apartments etc.), and geographic areas. Instead of developing yet another computer model, the author used the findings and recommendations of these feasibility studies to develop a fuel cell energy system retrofit scheme for specific application to three facilities typical of the types existing at WPAFB.

II. Literature Review

Air Force Policies and Goals

The 1985 Air Force Energy Plan lists several goals for reducing facility energy consumption. Goals applicable to this study are first, to install least life-cycle cost energy conservation retrofits in all buildings over 1,000 square feet in floor area; second, the use of advanced energy technologies to supply facility energy requirements; and third, a 45 percent reduction in the use of petroleum fuels from 1975 levels. All four of these goals are to be achieved by the year 2000 [7:53].

In support of these goals, the Air Force Engineering & Services Center (AFESC) at Tyndall AFB, FL has been assigned the responsibility for the research and development (R&D) of facilities energy systems. These systems include all heating and air conditioning systems and power systems that augment or replace commercial utilities. A major part of AFESC's R&D efforts is directed at monitoring the development of new facilities related technology. As new technologies become cost effective, AFESC recommends their incorporation into Air Force facility energy systems [7:13,84]. As one of these new technologies, fuel cell systems have proven to be cost effective in experimental installations such that routine installation of mass produced fuel systems is expected to begin in FY 89.

Additionally, current FY 86-90 funding for fuel cells is at $28 million. If fuel cell prices drop as expected, the Air Force expects fuel cells to supply approximately 0.266 trillion British Thermal Units (BTU) of facility energy by 1991 [7:71].

Advantages of Fuel Cell Systems

A fuel cell energy system has several significant advantages over conventional energy systems. First, fuel cells are very efficient- over 80 percent of the chemical energy released by the fuel can be recovered as electricity and heat. Second, they can operate at high efficiency under partial load. Third, they do not contribute significantly to air, water or noise pollution. Fourth, they can be designed to operate on several types of hydrocarbon fuels such as coal derived gas, distillates, methane, etc., as well as synthetic fuels currently under development. Fifth and finally, the fuel cell is modular, so that systems can be configured to match a wide range of load requirements [6:265-269].

The Fuel Cell

In order to obtain the desired magnitude of power output, fuel cell energy systems contain many individual fuel cells connected together in what are called "stacks". Several different types of fuel cells have been developed; however, their principles of operation are similar to that

of the hydrogen-oxygen type. This type of fuel cell consists of four main parts: a porous hydrogen electrode, an electrolyte, a porous oxygen electrode, and an electrical load (Figure 1) [2:28]. At the hydrogen electrode a source of hydrogen gas (H_2) is introduced, where it becomes chemisorbed (attached via a catalyst) to the electrode surface. The catalyst causes the hydrogen molecule to split apart into two individual hydrogen atoms by lowering the activation energy necessary to cause chemical reaction. The hydrogen atoms then migrate into the porous electrode, where each interacts with a hydroxyl ion (OH^-) to form water and to release two electrons. The electrons flow through the electrical load where the electron flow (current) performs work such as operating an electric motor, lights etc. The electrons then flow into the oxygen electrode where, in a similar process as occurs at the hydrogen electrode, the electrons combine with water molecules (H_2O) and oxygen (O_2) that has been previously chemisorbed into the electrode. The combination of two electrons with two oxygen atoms and one molecule of water produce a hydroxyl ion (OH^-) and a perhydroxyl ion (O_2H^-). The catalyst also helps break down the non-useful perhydroxyl ion into a useful hydroxyl ion and an oxygen atom. Finally, the hydroxyl ions migrate across the electrolyte to the hydrogen electrode to complete the overall chemical reaction [1:26-33; 12:338].

The function of the electrolyte is to act as a barrier between the electrodes to prevent the hydrogen and oxygen gases from combining directly and also to provide a medium through which the water molecules and hydroxyl ions migrate [2:32].

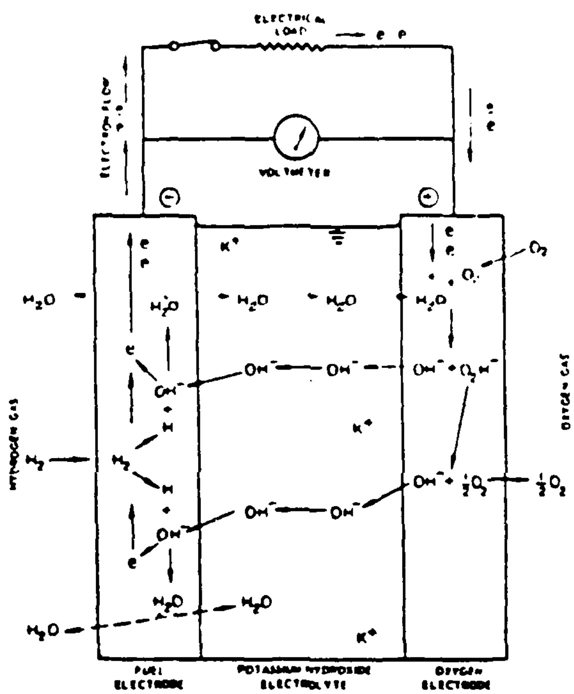


Figure 1. Schematic Diagram of a Hydrogen-Oxygen Fuel Cell [2:28]

Fuel Cell Efficiency and Losses

As previously described, fuel cells convert chemical energy directly into electrical energy without having to go through an intermediate step where thermal energy is added (e.g., the burning of coal or oil to produce steam in order to run a steam turbine-generator). For this reason, fuel

cells are inherently more efficient than conventional coal or oil fueled electrical generating plants. In fact, energy systems that depend on this intermediate step have a practical maximum efficiency of only 35 percent, while fuel cell systems have demonstrated efficiencies of over 80 percent if the heat generated by the fuel cell is utilized (e.g.,to augment facility space heating) [2:36; 7:71]. Fuel cell energy conversion losses are mainly due to the heat generated by the chemical reactions taking place within the cell, the resistance to current flow within the electrodes, and the loss of energy (i.e.,difference in potential or voltage) between the electrodes. This energy loss allows the hydroxyl ions to migrate across the electrolyte at a sufficient rate to produce an adequate amount of electron flow (current) [12:338].

Fuel Cell Energy System Components

A fuel cell produces direct current electricity with inputs of a fuel (hydrogen gas in this example) and air (a source of oxygen). Since most facilities require alternating current power and because pure hydrogen gas is not a commonly available fuel, two other components must be added to a fuel cell to form a practical energy system.

First, to produce pure hydrogen, a component called a reformer must be provided. This device processes liquid or gaseous hydrocarbon fuels (usually natural gas) with steam produced from heat generated by the fuel cell. This process

reduces or "cracks" the hydrocarbon molecules into their component parts, one of these parts being hydrogen gas. The second component required to make up a fuel cell energy system is an inverter. This solid state device takes the direct current produced by the fuel cell and converts it into alternating current. The output can then be fed into a transformer to obtain the desired voltage level (Figure 2) [2:21].

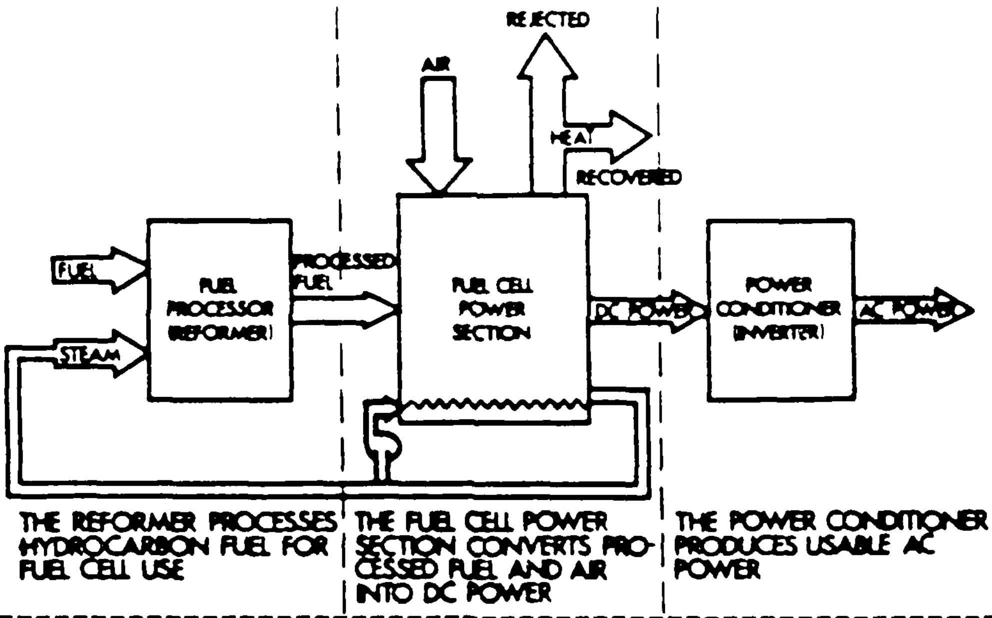


Figure 2. Block Diagram of a Fuel Cell Energy System [2:22]

Another component that is not directly related to producing electrical power, but is nevertheless essential for the fuel cell to operate, is the heat exchanger. This device performs the same function as an automobile radiator in that it removes excess heat generated, in this case, by the chemical reactions taking place in the fuel cell power section.

Present fuel cell system designs utilize two, water-to-water heat exchangers. One removes low grade heat up to 180 degrees Fahrenheit (°F), and the other removes high grade heat up to 275 F (Figure 3) [19:2-5].

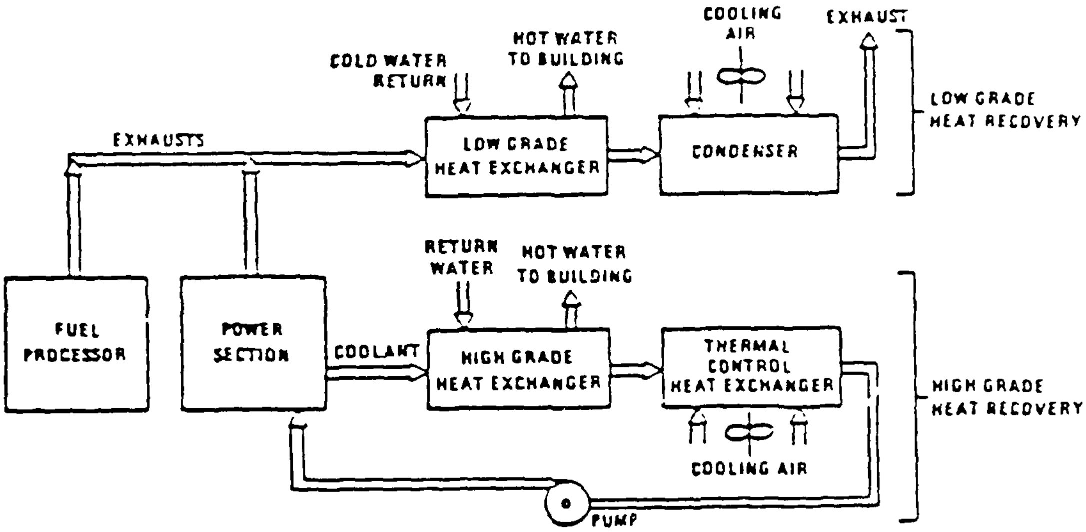


Figure 3. Fuel Cell Power Plant Heat Recovery System [2:22]

Also, Taylor states that the amount of heat a fuel cell can transfer is directly related to the temperature difference between the supply water (i.e., water heated by the operating fuel cell), and the return water(i.e., the supply water returned back to the fuel cell after thermal energy has been extracted). That is, the greater the temperature difference between the supply and return water, the greater the thermal energy or heat transfer rate [20:424]. Most facility heating systems; however, are designed with relatively small supply/return water

temperature differences. This fact tends to reduce the amount of fuel cell thermal energy that can be transferred efficiently.

Fuel Cell System Configurations

The Gas Powercel National Market Report [sic] cites two basic configurations for facility fuel cell power systems: grid connected and grid independent. A grid is simply a term used for the existing commercial electrical power network [13:4-5].

A grid connected system would be dependent on the electrical grid for peak power requirements above the capacity of the fuel cell electrical output. Conversely, the fuel cell could sell back electricity to the grid during time periods when the electrical demand of the connected facility is low.

A grid independent system would not use power from the grid except possibly as an emergency back up power source. The capacity of a fuel cell in this configuration would have to be sized to equal the peak electrical load of the facility. The main disadvantage of this configuration is the large quantity of unused capacity that would not be utilized during off-peak periods. The grid connected configuration, on the other hand, allows a variety of operation modes that can be matched to the electrical and thermal load patterns of the facility proposed for fuel cell power application [13:4-6].

The Report also describes four system operating modes: fixed power level, electric load following, thermal load following, and programmed operation [13:4-5]. Operating a fuel cell in a fixed, maximum power level mode has the advantage of allowing the fuel cell to operate at its maximum efficiency, but only if the power capacity of the cell is kept small enough so that it can be run at full power continuously. The disadvantage of the fixed power mode of operation is that the amount of the total facility energy requirement that can be supplied is only about 30 to 40 percent (Figure 4) [13:10].

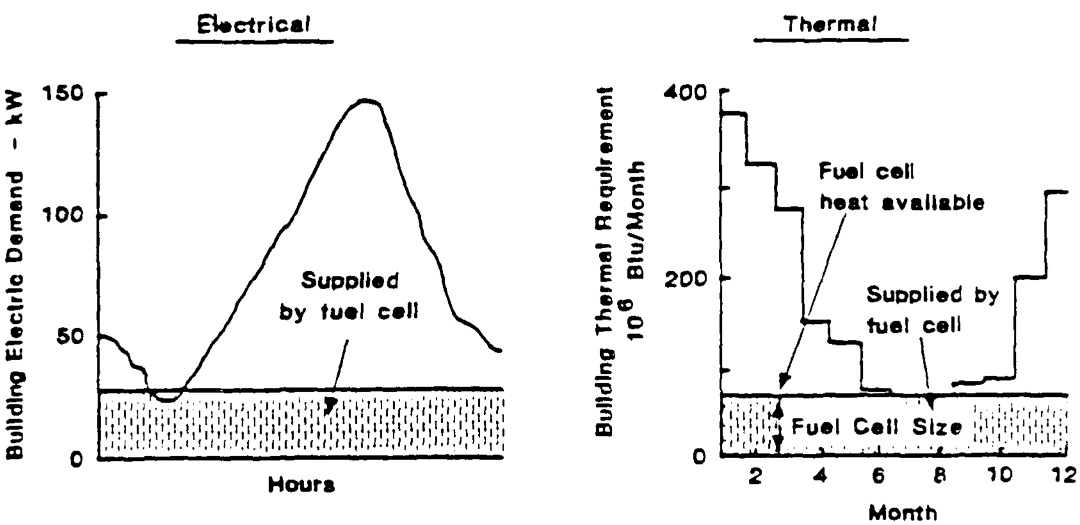


Figure 4. Fuel Cell Operation In Fixed Power Level Mode [13:4-9]

Both electrical and thermal load following modes are similar in that either the facility electrical or thermal load requirement is monitored by a control system that, in turn, adjusts the level of the fuel cell output to match

that of the load monitored. For example, a typical fuel system operated in an electrical load following mode would provide electrical power up to the capacity of the fuel cell. Additional load requirements would be met by the connected grid. Thermal load requirements would be met in varying degrees depending on the facility thermal to electric load ratio. Additional thermal load requirements would be met by the existing furnace, boiler or other thermal energy source of the facility [5:8,9].

Finally, the programmed mode of fuel cell system operation combines the advantages of all three of the previous modes of operation by means of a more complicated load monitor and control system. This system would be able to switch from mode to mode to provide the most energy for the lowest cost. The system designer would determine the mode switch points by comparing purchased energy cost with the cost of energy produced by the fuel cell system in providing the electrical and thermal load requirements of the facility [13:4-12].

Recent Feasibility Studies

Aimone describes a study completed in 1979 by United Technologies Corporation in which several building types (offices, restaurants, apartments) in various geographic locations were examined to determine the energy and economic trade-offs between a fuel cell-heat pump energy system that satisfied facility electrical and heating requirements and

the existing gas fired furnaces that provide heat only for each facility. The major findings of the study were first, that the fuel cell-heat pump system energy savings ranged from 10 to 50 percent depending on the type and location of the facility, and second, that both the energy savings and the life cycle cost of the system depends heavily on the ratio of the thermal to electric energy requirements of the facility. Specifically, if a facility requires thermal energy (space heating, hot water) in an amount at least four times that of the electrical energy required (measured in equivalent thermal units of BTU's) then the fuel cell system will consume less natural gas fuel in providing both the electrical and thermal energy requirements of a facility than that consumed by the existing gas furnace system in providing thermal energy only (Figure 5). As the thermal to electric energy ratio drops below four, the existing gas furnace system becomes more cost effective because increasing amounts of thermal energy generated by the fuel cell would not be utilized and would have to be either stored at an additional cost or ejected into the atmosphere. In summary, this study showed that it is important to use the heat generated by a fuel cell system to the maximum extent possible in order to achieve maximum cost effectiveness [2:75-85].

Trocciola evaluated the feasibility of using a megawatt size fuel cell power plant to supply the electrical and

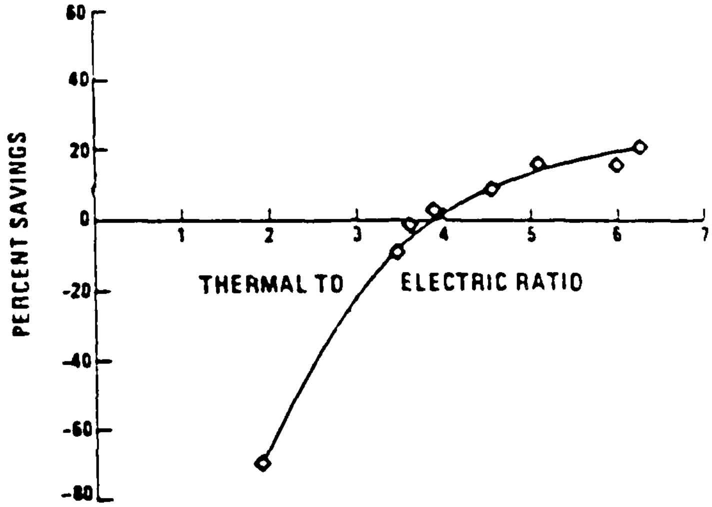


Figure 5. Thermal to Electric Ratio [2:83]

thermal requirements of the Air Logistics Center (ALC) at Tinker AFB. The power plant selected for the study was an 11 megawatt phosphoric acid fuel cell system. The nominal operating parameters of this system were developed by the Electric Power Research Institute in 1981.

The study began by describing various performance, environmental and cost pay back parameters required to meet the ALC mission and then compared the 11 megawatt system with each parameter. Cost comparisons were made with the fuel cell system that included either 50 percent or 100 percent generated heat usage versus using electrical power from the existing base grid, as well as, versus a grid plus emergency diesel generator system (Figure 6).

As can be seen from Figure 6, the fuel cell system compared favorably with both conventional utility systems.

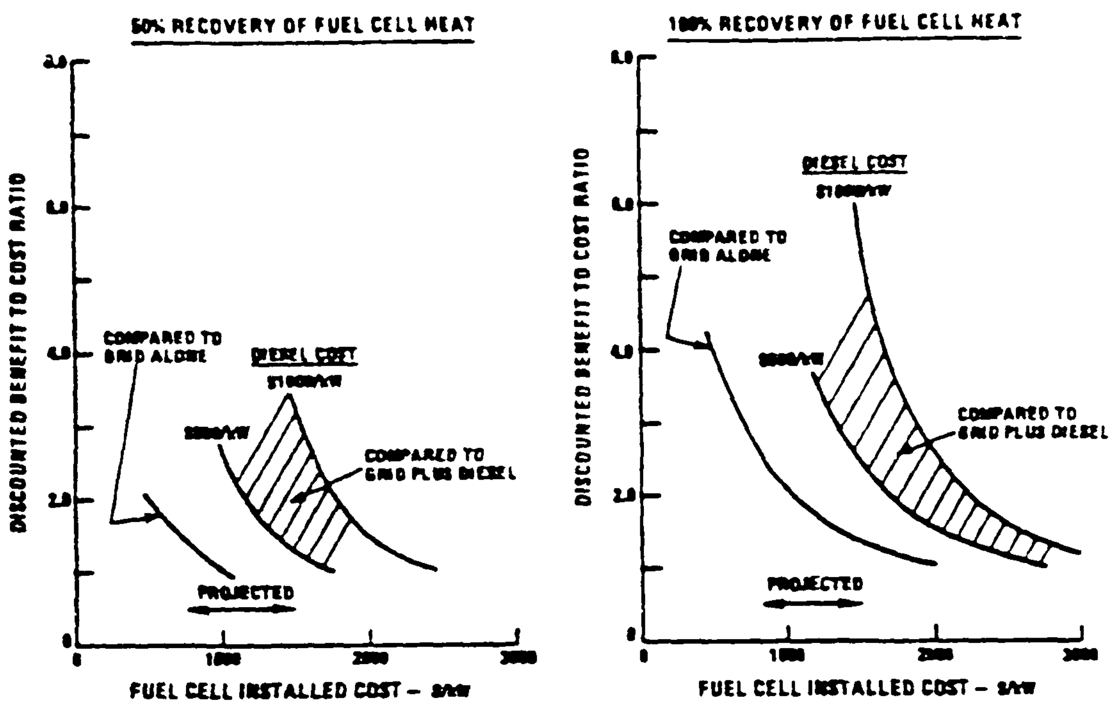


Figure 6. Discounted Benefit to Cost Ratio for Fuel Cells [21:5-12]

For example, for a 50 percent recovery of heat, a fuel cell system can have an installed cost of as much as $1000 per kilowatt (KW) and still have a benefit to cost ratio of (i.e., break-even cost) of "1". Trocciola also notes that since the fuel cell system is independent from electric utility outages, it can be used as the primary source of power with the commercial grid assuming the role as an emergency power source. Thus, the fuel cell system has an additional advantage of eliminating the need for emergency generators [21:2-7 - 6-1].

The studies reviewed indicate that the thermal output of a fuel cell must be effectively utilized to reduce the cost of providing thermal energy to a facility, before a fuel cell power system can be cost competitive with existing facility energy sources. However, the thermal transfer system (i.e., heat exchangers, piping, pumps and controls) may be too costly to achieve a cost to benefit ratio of "1" or greater. The existing thermal energy generation and distribution system of a particular facility may or may not be able to be modified to allow fuel cell thermal energy to be transferred within economic feasibility limits. For this reason, the application of a fuel cell system is site specific.

It was the author's intent then, to determine if a fuel cell energy system would be economically feasible if installed in three, site specific facilities representative of the main facility types at WPAFB.

III. Methodology

Overview

In determining what facilities on WPAFB were to be studied, personnel from the 2750th Civil Engineering Squadron were contacted to obtain data on current energy costs, actual or estimated values of electric and thermal energy loads for various facilities, and related subjects. A selection of facilities was made based on the amount and quality of facility energy consumption data available, the thermal and electric load requirements of the facility, and the author's desire to evaluate a cross section of facility types on WPAFB.

Performance characteristics and configurations of fuel cell energy systems were obtained by surveying additional literature from the Department of Energy, the Gas Research Institute, United Technologies Corporation, and other sources. The author evaluated and compared energy consumption data and design information from fuel cell energy system reports with desired characteristics of system simplicity and low installation and maintenance costs. The results of this evaluation process were used to develop an energy system configuration capable of supplying a certain percentage of the total facility energy needs more efficiently, for each of the facilities selected for study.

Life cycle costs were developed to compare each proposed system with the existing facility energy system. Finally, a sensitivity analysis was attempted to determine at what cost per kilowatt a fuel cell energy system at WPAFB would be cost competitive with commercially supplied electric power.

Facility Selection

Three factors were involved in the selection of facilities for this thesis: the metered facility energy consumption data available, the thermal and electrical load requirements of the metered facilities, and the logical desire to study a reasonably good cross section of facility types on WPAFB.

A historical record source for metered energy consumption of 22 individual facilities, plus energy consumption for two Military Family Housing (MFH) areas, was located at the utility monitoring and billing section (DEEX) of the 2750th Base Civil Engineer. The metered data consists of half-hourly consumption readings for electricity and steam or high temperature hot water, and a graph showing peak, average, and low consumption levels for each hour of the day for a month long period [24]. A sample of this data is located in Appendix A. The advantage of having metered energy consumption available was that it eliminated the need to make many of the consumption estimation calculations contained in several other fuel cell studies reviewed.

A decision had to be made when the other two facility selection factors were addressed. In order to obtain a good cross section of the various types of facilities on WPAFB, facilities were chosen that did not have relatively coincident thermal and electrical loads nor advantageous thermal to electric load ratios. It was the author's intent to study three facilities representative of the types on WPAFB, regardless of their thermal/electrical usage patterns, because it would be useful to know at what purchased utility cost a break-even point could be reached for typical base facilities (e.g., for future fuel cell system installation programming purposes).

Three metered facilities that the author felt were representative of a significant number of facilities on WPAFB were; first, Page Manor MFH units; second, an office/classroom type facility, the School of Systems and Logistics, Air Force Institute of Technology, Building 641; and third, an office/laboratory type facility, Reconnaissance Systems Evaluation Lab, Building 485.

Determination of Fuel Cell System Configuration

Recent studies of various fuel cell system configurations attempt to find ways to maximize the use of the thermal energy generated by the fuel cell for the least cost. All of the studies surveyed integrated the fuel cell into the existing facility energy system where practical (e.g., gas boilers were retained to augment the thermal

energy supplied by the fuel cell). The systems developed in these studies varied considerably in complexity.

The 40KW test system installed at the Air Force Museum, WPAFB, used simple, hot water coil space heaters to utilize the fuel cell thermal output [20:2]. One system, proposed by Wakefield, for an apartment building would use multiple energy transfer components. The fuel cell would provide electrical power to satisfy the building demand, plus operate a vapor compression chiller to provide chilled water air conditioning. An absorption chiller, fueled by hot water supplied from the fuel cell and an existing hot water boiler, would provide additional chilled water to augment the vapor compression chiller. Space heating and domestic hot water would be supplied by the fuel cell thermal output, a heat pump with electrical resistance powered by the fuel cell, and finally, by additional hot water from the existing hot water boiler. All of these systems would be integrated via water pumps, piping, mixing valves, and a monitor/control system [22:4-36]. The majority of studies surveyed, however, were developed around fuel cell systems of moderate complexity.

In order to determine the proposed complexity level for the fuel cell system studied in this thesis, the author recognized that adding complexity almost always increases cost and reduces reliability. This is especially true when the main component of the system under study, the fuel cell,

is still in the experimental development stage. While a more complex system would probably increase energy savings, the author felt that determining the feasibility of a relatively simple fuel cell system would be more logical given the still largely estimated operational capabilities of the fuel cell.

The fuel cell energy system proposed for the multi-unit MFH facilities consists of a central fuel cell with a hot water distribution system that would serve MFH clusters of 5 to 19 units in size. The fuel cell would be grid connected to the existing electrical system and provide a portion of the electrical load requirements of the housing cluster. Space cooling would continue to be provided by the existing unitary air conditioners. The fuel cell thermal output would augment the domestic hot water requirements of the housing cluster by means of a water-to-water heat exchanger installed inside a central, hot water holding tank connected via underground piping to the existing gas hot water heaters located in each MFH unit.

Hot water flow from the holding tank to the facility would be regulated by a temperature modulated, three-way valve to permit maximum utilization of the hot water generated by the fuel cell. That is, the valve controlling the fuel cell heat exchanger output would open first. Then, as the requirement for hot water increased above the quantity that could be supplied by the fuel cell, the valve

Legend for Figures 7 & 8

E: Electrical Power
 a. Commercial Grid
 b. Fuel Cell Output

EX: Existing Steam Converter, Bldg.641; or Boiler, Bldg.485

G: Grid Interconnect Unit

FC: Fuel Cell

HEX: Heat Exchanger
 a. Water-to-water
 b. Water-to-air

HWR: Hot Water Return

HWS: Hot Water Supply

NAG: Natural Gas

T: Hot Water Storage Tank

WH: Water Heater

: Water Pump

: Three-way Valve

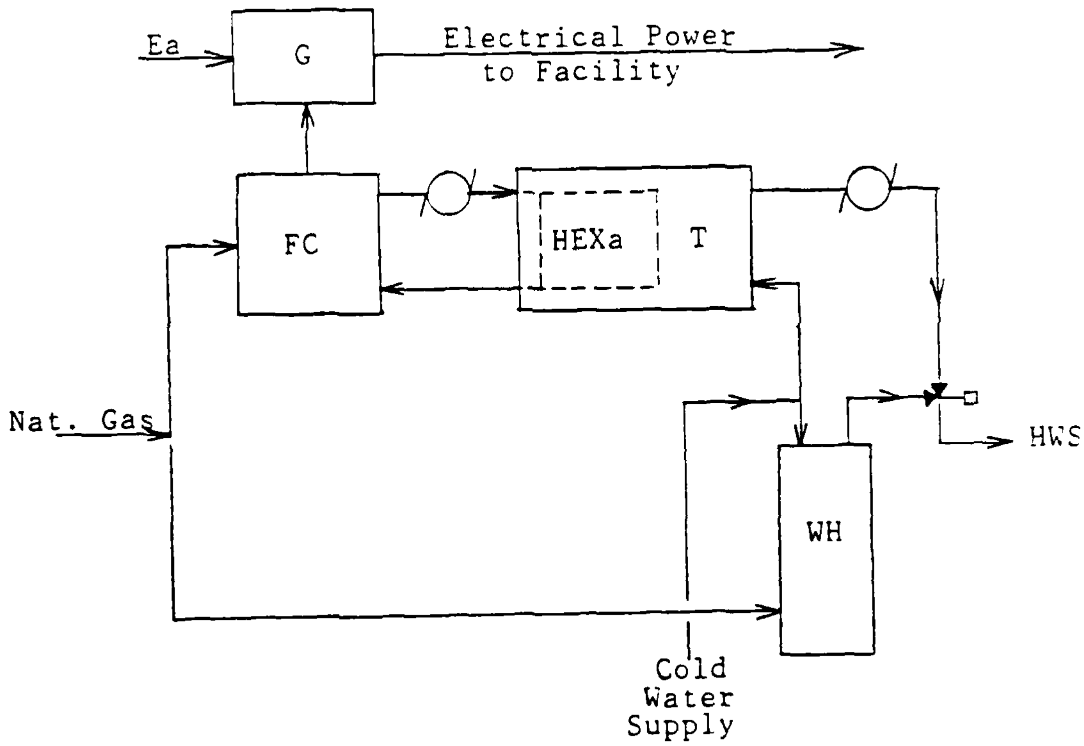


Figure 7. Proposed MFH Fuel Cell System

controlling the output of the water heater would open to satisfy the additional requirement (Figure 7).

The fuel cell systems proposed for the other two facilities are similar. Both facilities have large, central, heating, ventilating and air conditioning (HVAC) systems. Unlike the MFH system, the main use of the thermal output of the fuel cell would be for space heating. Hot water from the integral fuel cell heat exchangers would be pumped through water-to-water heat exchangers installed in the facility hot water supply main line, thereby transferring the fuel cell thermal output to the facility hot water distribution system. As in the MFH system, the flow of the fuel cell generated hot water would be controlled by a thermostatic, three-way valve (Figure 3).

Additional thermal energy from the fuel cell could have been extracted via water-to-air heat exchanger coils installed in the facility HVAC duct systems; however, the cost to modify the HVAC system would have been prohibitive. In Acre's study involving a proposed fuel cell installation at McClellan AFB, CA, he determined that the cost of providing large (area) heat exchangers and extensive duct modification required to allow a reasonable amount of thermal energy transfer from the fuel cell to the facility would have been too expensive relative to the energy savings incurred [1:51].

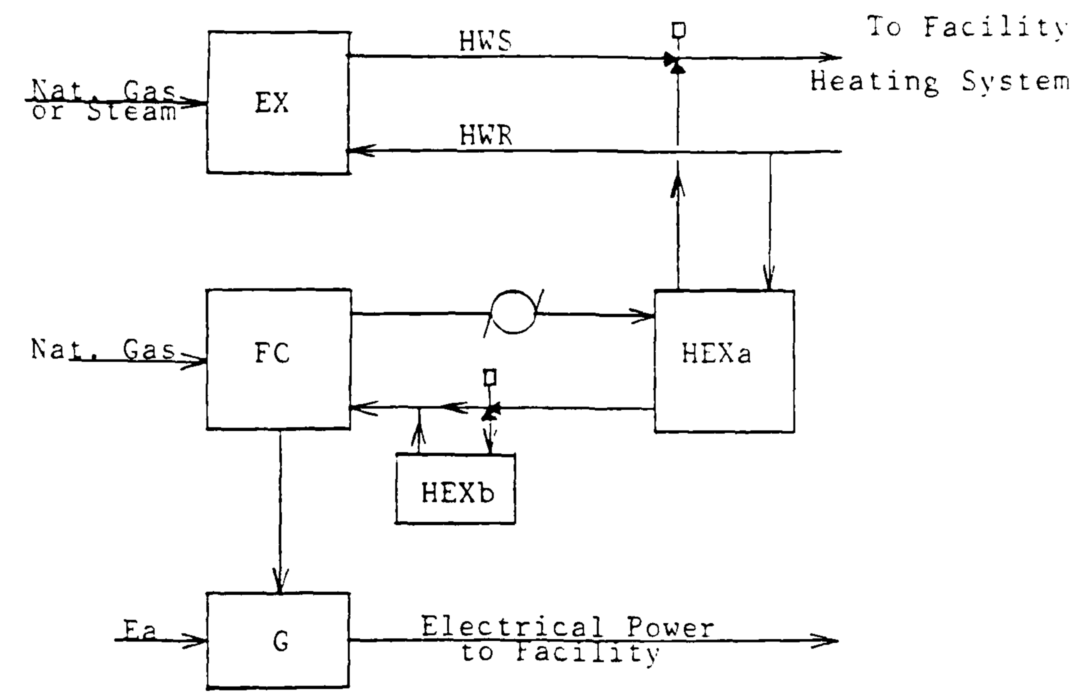


Figure 8. Proposed Large Facility Fuel Cell System

Fuel Cell Sizing

Bollenbacher's study revealed that the optimum size for a fuel cell power plant was a strong function of the commercial natural gas and electricity rates available at the proposed site [5:21]. He developed a series of graphs that showed linear plots of the estimated optimum fuel cell size for various natural gas and utility costs in 1981 dollars. The author plotted the FY 81 gas and electricity costs, $4.29/10^6 BTU and $11.80/10^6 BTU respectively, for WPAFB on these graphs and found that the optimum fuel cell size ranged from 10 to 30 percent of the peak electricity load of the facilities examined in Bollenbacher's study

(Figure 9) [5:18]. These percentages changed only slightly when the cost of steam ($4.10 per 10^6 BTU, used in lieu of natural gas as the heat source in one of the office facilities in this thesis) was substituted for natural gas. These percentage boundary limits were used as one constraint to determine fuel cell size.

An additional sizing constraint was the desire to keep the fuel cell running continuously and at a power level of at least 50 percent (Figure 10). This mode of operation keeps the operational efficiency of the fuel cell on a high level, thus allowing maximum cost benefit to be achieved. Also note that the thermal output of the fuel cell is relatively constant above the 50 percent power level. This fact brings up the final sizing constraint which is based on the facility monthly thermal energy consumption.

As stated previously, the thermal energy generated by a fuel cell must be utilized to the maximum extent possible to reduce the overall cost of providing electrical and thermal energy to a facility. For this reason the annual thermal output of a fuel cell size chosen within the 10 and 30 percent band should not be greater that the annual facility thermal requirement. However, this final constraint may not be able to be followed if the facility thermal requirement is smaller (or larger) than the thermal output of the 10 percent (or 30 percent) sized fuel

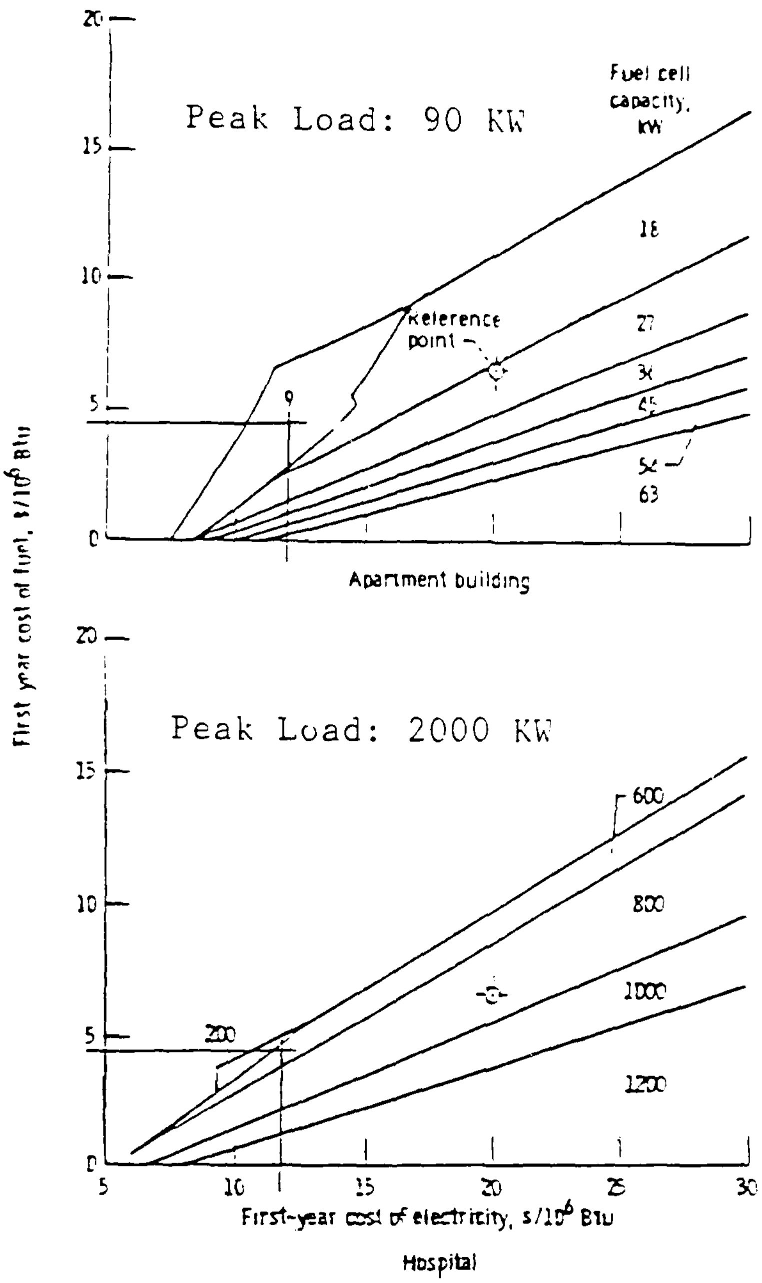


Figure 9. Fuel Cell Size Determination Using Electricity and Natural Gas Costs [5:Fig 14]

cell. In such cases, the life-cycle cost analysis would be based on the smallest (or largest) fuel cell size within

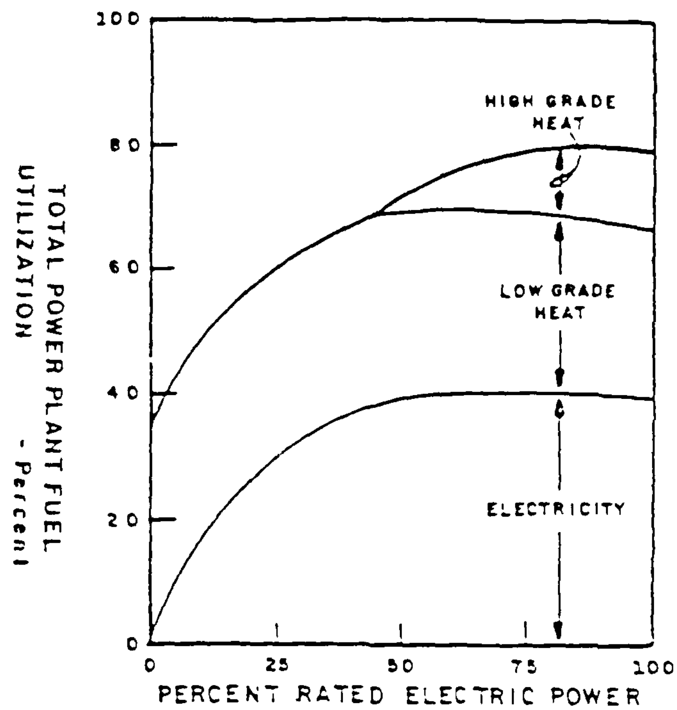


Figure 1Ø. Fuel Cell Operating Efficiency [6:266]

the constraint band.

The fuel cell sizing boundary limits, operating power level, and annual facility thermal requirement constraints were analyzed with metered energy consumption data for the facilities studied. In order to perform this analysis, records of the average electricity consumption of four months representative of the seasons (January, April, July, and October) were obtained for each facility from the 275Øth Base Civil Engineer utility monitoring section (Appendix A). Six electricity consumption values were then chosen at four hour intervals from each of the four, monthly consumption records for each facility. Each of these six sets of four

consumption values was averaged and then plotted to produce an average daily facility electrical load graph. The fuel cell size boundary limits were overlaid on these graphs, and the size of the fuel cell was then determined for each facility using the minimum operating power level and the annual facility thermal requirement constraints as weighting factors for choosing the percentage size value within the boundary limits. Figure 11 is a sample illustration of this process. Note that the peak demand value listed is higher than the highest point on the graph. This is because average demand values were used to develop the graph. To determine the size of the fuel cell, note that a 50 KW unit would be able to operate at a power level of at least 50 percent capacity since the lowest average electrical demand level is 25 KW. However, the annual facility thermal energy consumption of 1,500 K(thousand)BTU's is less that the maximum annual thermal output of a 50 KW fuel cell of 1,642.5 KBTU's. Therefore, the adjusted fuel cell size would be (1500 KBTU/1625.5 KBTU) x 50 KW = 45.7 KW. This sizing process is described in more detail in Appendix C.

System Cost Estimate

The fuel cell system cost estimate addressed three areas: the fuel cell power plant cost, the electrical and thermal interface costs, and the annual operation and maintenance costs.

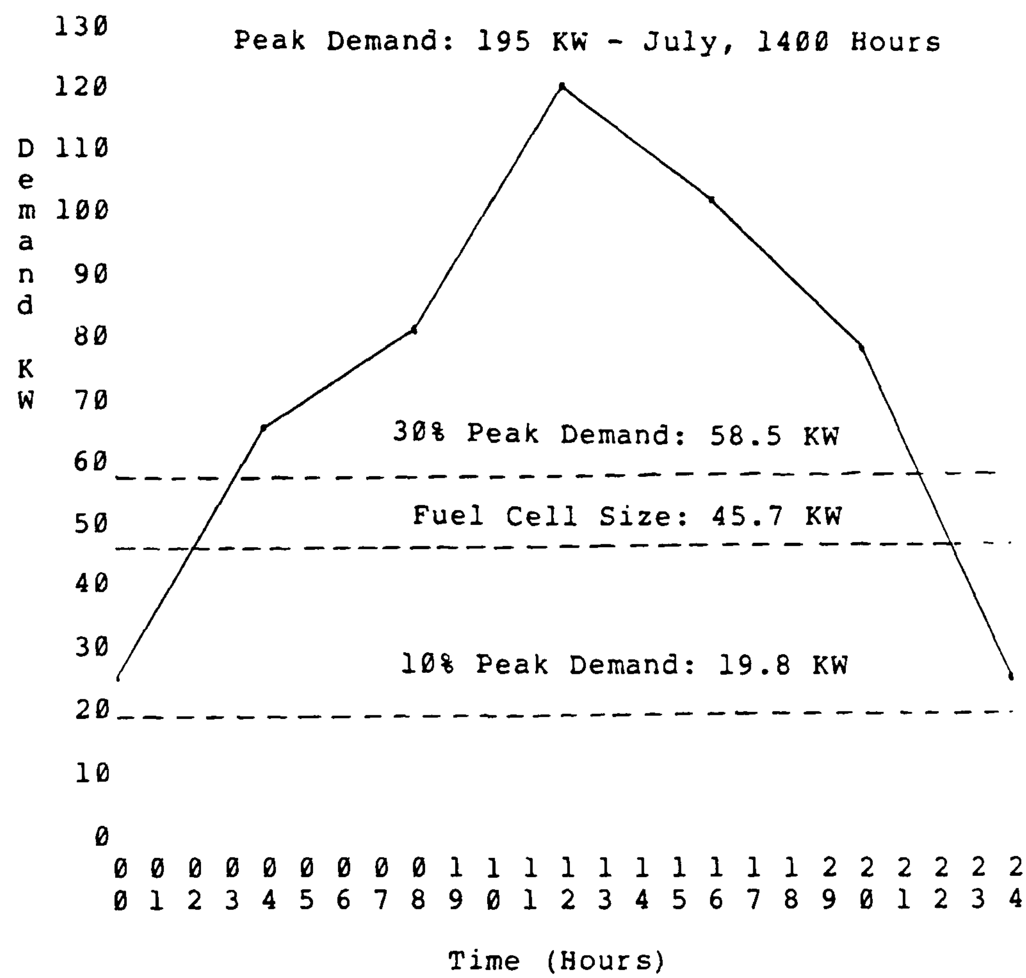


Figure 11. Fuel Cell Sizing Example

In an attempt to obtain an approximation of the cost of a fuel cell power plant, several studies were reviewed [5,17,22]. Estimated installed costs for fuel cell power plants of common size were found to range from $820/KW to $1509/KW. Because of this wide cost variance, three system costs were developed (based on the low, average, and high estimated fuel cell costs) for use in the life-cycle cost analysis.

The thermal and electrical interface costs were determined by conventional construction cost estimating techniques, using material and labor costs contained in cost estimating manuals.

Operation and maintenance(O&M) cost estimates, like those for the fuel cell power plant, varied significantly. Annual fixed O&M costs ranged from $15.33 per KW of fuel cell size to 2.5 percent of the fuel cell power plant cost, and the range of variable O&M costs was $.009 to $.021 per kilowatt-hour of annual fuel cell power plant production. Thus, three corresponding O&M cost values were calculated (low, average, and high) and applied to each of the three fuel cell power plant costs.

These sets of fuel cell power plant and O&M cost data were used in the life-cycle cost analysis to develop a set of benefit to cost ratios. It was the author's intent to plot these ratios versus total fuel cell system cost per KW to determine the sensitivity of a fuel cell energy system to changes in the fuel cell power plant and O&M costs. Figure 6 is an example of this graphical process.

Life-Cycle Cost Analysis

Life-cycle cost calculations were made following the prescribed format contained in Engineering Technical Letter (ETL) 82-4: Energy Conservation Investment Program (ECIP). The following constraints stated in ETL 82-4 applied to this analysis:

a. Fuel cell economic life - 25 years.

b. Actual (1986) facility energy costs formed the base values for the analysis.

c. Annual energy cost escalation - 7 percent.

Appendix G contains applicable excerpts from attachment 1 to ETL 82-4, Life-Cycle Cost Analysis Summary, which describes a step by step process for completing a cost analysis summary. The deciding factor used to determine if a project is cost effective or not is the savings to investment ratio. This ratio consists of the total life-cycle energy savings in dollars divided by the total investment cost of the energy saving project. Thus, the savings to investment ratio is simply another name for the benefit to cost ratio mentioned heretofore.

Three types of costs were required to complete the life-cycle cost analysis summary. The first was the investment cost. This cost was the total installed cost of the fuel cell energy system minus any salvage value. Note that the construction cost was multiplied by an energy credit cost reduction factor of 0.9. This factor is based upon a ten percent tax credit allowed by the DOE for energy conservation projects. The second type of cost required for the cost analysis was the difference in energy use between the existing system and the proposed system. Annual increases and/or decreases in consumption of the fuels applicable to the study were calculated and then converted

into dollars. These annual savings and/or cost values were then converted to a single, present worth value using the uniform present worth discount factors contained in Appendix G, Table XV. The third type of cost, non-energy cost, was calculated in a similar manner. This cost was divided into two additional categories- recurring (e.g., operations and maintenance) cost, and non-recurring (e.g., parts replacement) cost. However, the cost value used in this section was the annual recurring O&M cost that contained both fixed and variable costs. Thus, the non-recurring cost part of the life-cycle cost summary was not used. Therefore, a single, present worth cost value was calculated using the annual recurring O&M cost value.

Finally, the energy and non-energy present worth costs were added together and then divided by the total investment cost to obtain the savings to investment (i.e., benefit to cost) ratio [6:1-3].

IV. Determinations and Findings

Existing Energy System Consumption

The electrical demand data used to develop the average daily electrical load graphs for the three facilities examined in this thesis is contained in Appendix A. The particular values that were used to determine an average daily electrical demand value at six, four hour intervals are shown bounded by a rectangle. Table I lists these values, plus the average of each set. These set average values were the six data points used to plot a graph of the annual average of daily electrical demand for each of the three facilities examined. Note that the demand values used in the graph of the Page Manor MFH were for an individual unit. That is, the annual average demand values listed in Table I were divided by the total number of individual MFH units (i.e., 1,471).

The monthly and annual thermal energy consumption for each facility is listed in Table II. Average daily thermal demand graphs were not required, because the fuel cells, as sized, operated at either full load or close to full load continuously. Thus, the thermal output of all three fuel cells was relatively constant. Therefore, the thermal energy supplied to each facility was not demand dependent, and only the total annual thermal requirement of each facility was needed to determine what fraction of

Table I

Average Monthly and Average Annual Electrical Demand (KW)

Page Manor MFH

Time	Jan	Apr	Jul	Oct	Annual Average
0400	1096	964	1232	990	1070
0800	1528	1310	1512	1434	1446
1200	1720	1626	2214	1646	1801
1600	1722	1676	3828	1856	2270
2000	2294	2114	3572	2310	2572
2400/0000	1478	1370	2544	1268	1655

Building 641

Time	Jan	Apr	Jul	Oct	Annual Average
0400	42	44	130	92	77
0800	104	116	204	176	127
1200	118	132	214	196	165
1600	106	122	166	160	138
2000	60	74	106	120	90
2400/0000	32	30	52	58	43

Building 485

Time	Jan	Apr	Jul	Oct	Annual Average
0400	96	144	178	100	129
0800	142	184	230	150	176
1200	150	196	234	154	175
1600	150	186	224	130	172
2000	100	148	186	102	134
2400/0000	94	144	182	96	129

facility thermal energy was supplied by each fuel cell system.

Fuel Cell Sizing

Using the annual average electrical load values from Table I, fuel cell sizing graphs were drawn (Figures 12, 13 and 14). Sizing boundaries of 10 and 30 percent of

Table II

Facility Thermal Energy Consumption (KBTU)

Month	MFH Unit Cluster	Building 641	Building 485
Jan	18,930	183,032	713,227
Feb	"	124,106	652,521
Mar	"	64,675	794,725
Apr	"	6,789	424,258
May	"	6,463	281,154
Jun	"	0	400,949
Jul	"	0	350,000
Aug	"	3,200	"
Sep	"	5,727	"
Oct	"	4,948	"
Nov	"	15,160	310,440
Dec	"	176,562	535,810
Total	227,166	590,612	5,513,084

facility peak demand, plus the minimum operating power level and annual facility thermal requirement constraints were then applied.

In the case of Page Manor MFH, additional sizing constraints were imposed in order to determine the fuel cell size for a typical MFH unit cluster instead of only for a single MFH unit.

In order to minimize the cost of distributing thermal energy recovered from the fuel cell and make maximum use of the existing MFH low voltage electrical distribution system, sizing corresponded to clusters of MFH units with common electrical distribution systems. Although the MFH unit clusters vary in size from 5 to 19 units, the majority

of unit clusters were found to be in the range of 6 to 10 units. Therefore, an average unit cluster size of 8 was chosen for evaluation. Table III shows the results of the sizing calculations performed in Appendix C. Note that the fuel cell sizes chosen were below the areas where the electrical demand fluctuates. The small dip in the MFH demand plot, between 0230 and 0630 hours, amounted to only about a 1.5 percent difference in the total daily fuel cell electrical output and was therefore considered insignificant. Thus, the fuel cell power plants chosen operate in the fixed power level mode (i.e., at 100 percent rated power continuously).

Table III

Fuel Cell Power Plant Size

Facility	Power Plant Size (KW)
MFH Unit Cluster	7
Building 641	28
Building 485	94

The fuel cell sizes determined were not rounded up to possible future generic sizes of say, 10 KW and 100 KW, because the author expects future fuel cell designs to be sufficiently modular to allow fuel cell "stacks" rated at 2 KW, for example, to be combined until the desired KW rating is produced.

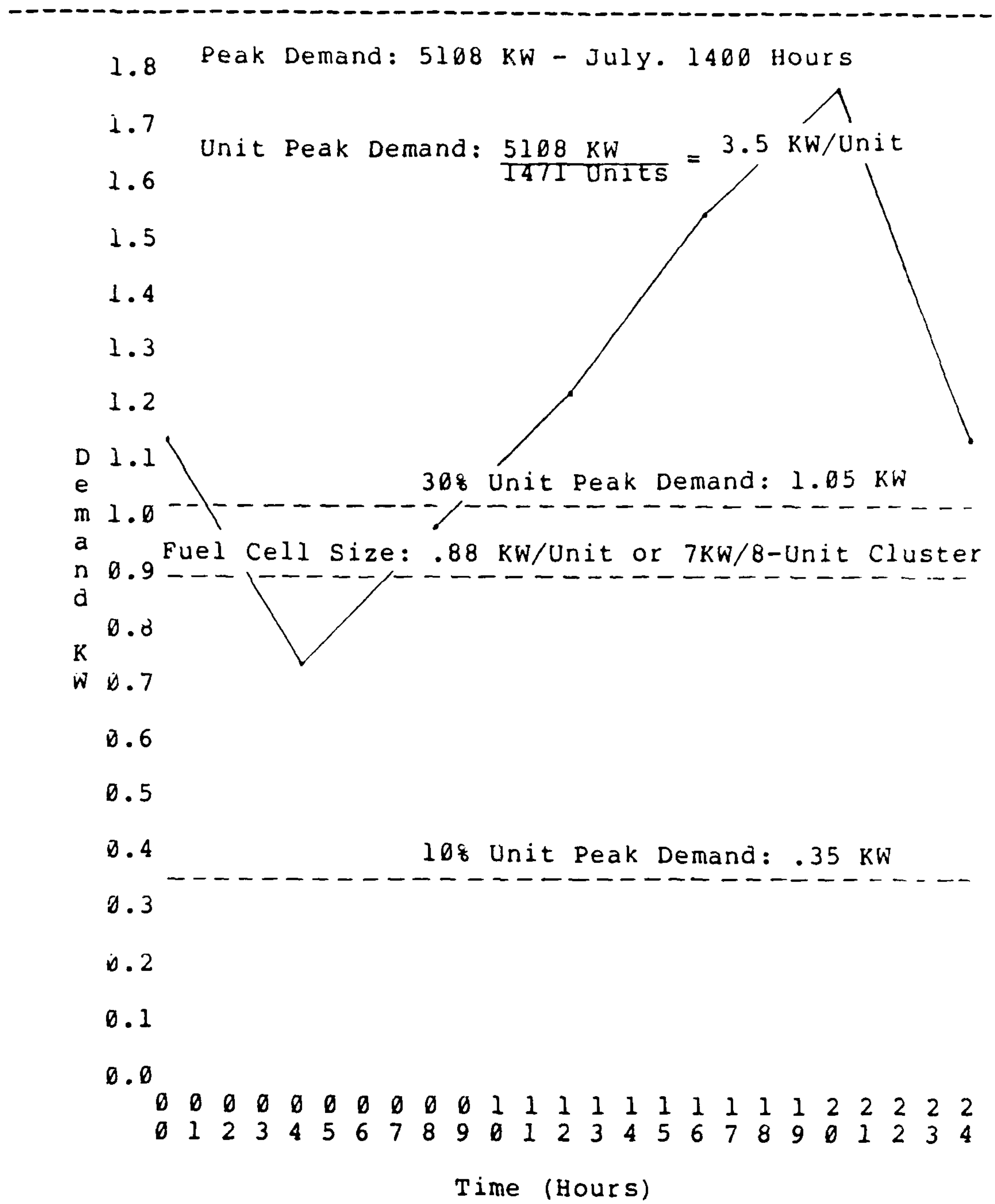


Figure 12. Annual Average of Daily Electrical Demand: Individual Page Manor MFH Units

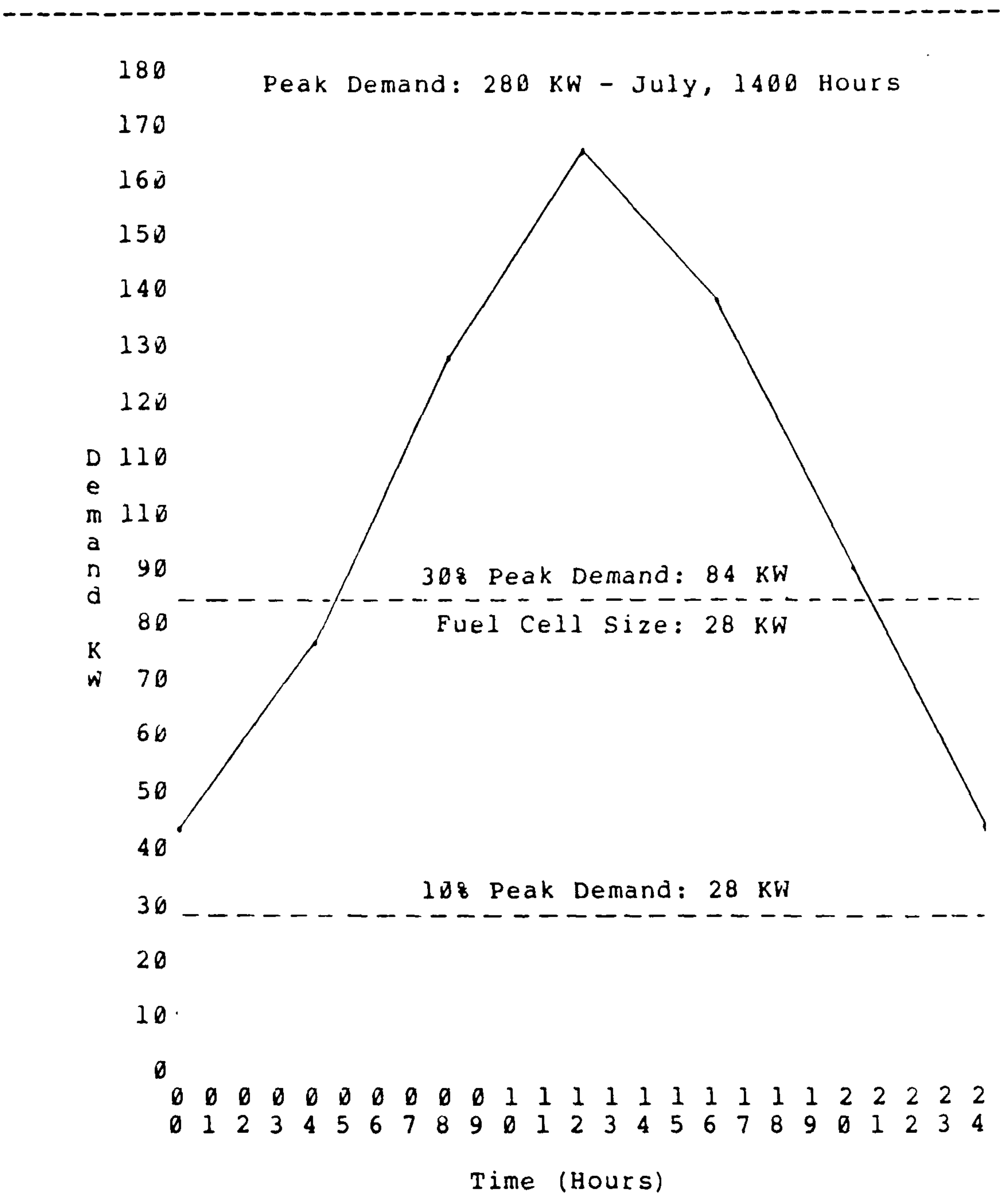


Figure 13. Annual Average of Daily Electrical Demand: AFIT, Building 641

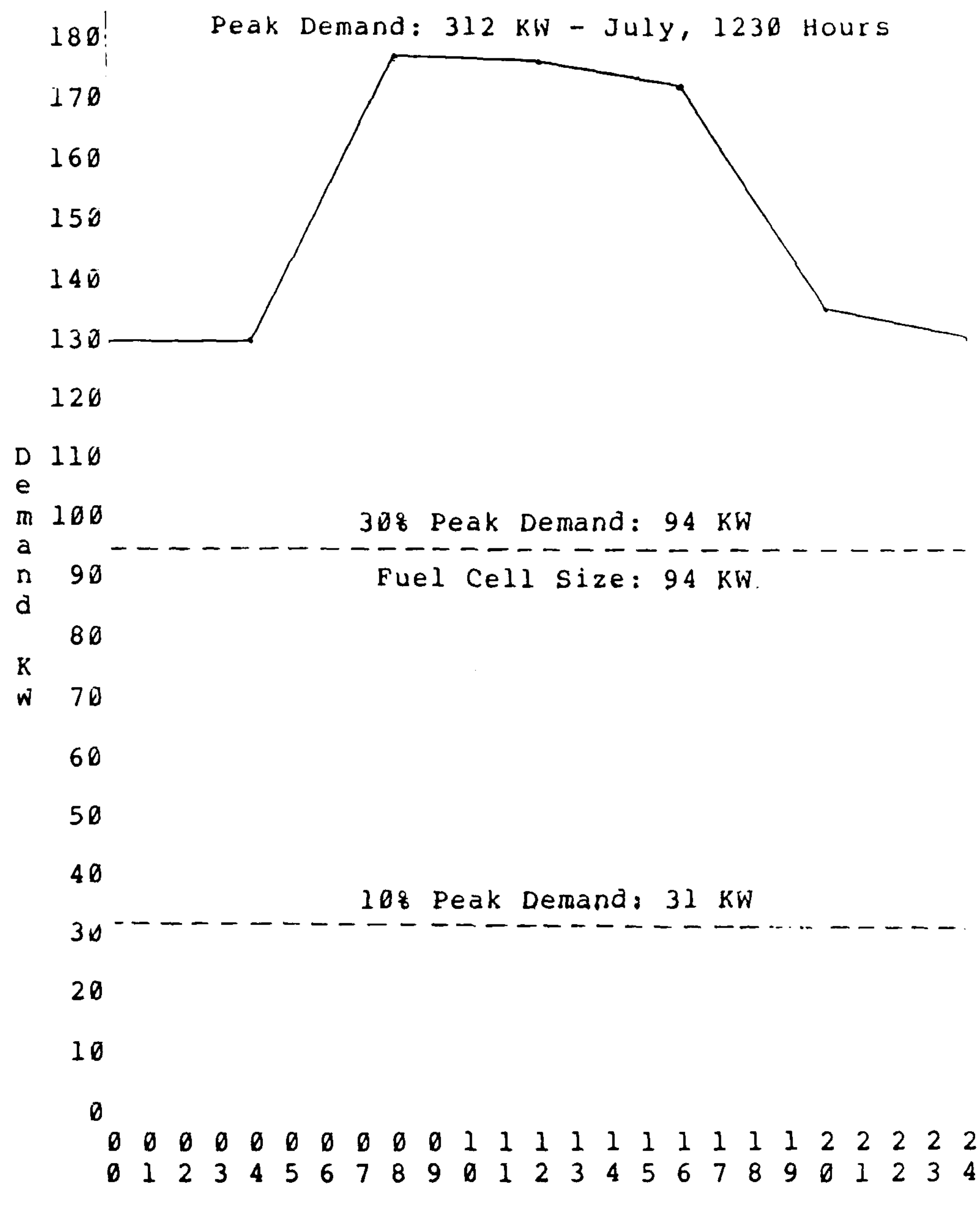


Figure 14. Annual Average of Daily Electrical Demand: Reconnaissance Systems Lab, Building 485

Fuel Cell Thermal Energy Transfer

The fuel cell power plant thermal output calculated in Appendix C was transferred to each facility through the fuel cell heat exchangers and thence to the facility heating system by means of another water-to-water heat exchanger located inside the facility mechanical room or, in the case of the MFH unit cluster, located next to a central, hot water storage tank near the fuel cell power plant.

In order to determine how much of the fuel cell heat was actually transferred to the facility heating system, the gallons per minute (gpm) flow of heated water required from the fuel cell heat exchangers had to be calculated. This heated water flow rate was then used with fuel cell and facility heat exchanger performance data to determine the quantity of thermal energy transferred to each facility. Table IV summarizes the quantities calculated in Appendix D.

Table IV

Fuel Cell Energy System Thermal Transfer

Facility	Thermal Transfer	Percent Fuel Cell Thermal Output
MFH Unit Cluster	13,130 BTU/hour	50%
Building 641	37,100 BTU/hour	35%
Building 485	124,350 BTU/hour	35%

The author determined that for Buildings 641 and 485 the thermal output from the fuel cell could be obtained only from the high grade heat exchanger. The reason for this was because the large flow rate of high temperature water required made it thermodynamically impossible to mix any of the low grade heat exchanger water with that of the high grade heat exchanger.

Fuel Cell Energy System Cost Estimate

Fuel Cell Power Plant. Table V summarizes the cost data used to determine three sets of fuel cell power plant costs used in the life-cycle cost analysis. All costs were escalated to 1986 dollars by means of historical cost indices contained in Means Electrical Construction Cost Data 1986. A sample cost escalation calculation is contained in Appendix B.

Table V

Fuel Cell Power Plant Cost Data

Source	Power Plant Installed Cost/KW	O&M Costs Fixed -- Variable
[5:33]	$1509	2.5% -- $.009/KWH System Cost
[17:28]	$1347	$15.33/KW -- $.021/KWH
[22:S-23]	$820	None -- $.016/KWH

The installed cost ranges (low, medium, and high) of the three fuel cell sizes previously determined are summarized in Table VI.

Table VI

Fuel Cell Power Plant Installed Cost Ranges ($000)

Facility	KW	Low($820/KW)	Avg($1347/KW)	High($1509/KW)
MFH Unit Cluster	7	5.7	9.4	10.7
Bldg. 641	28	23.0	37.7	42.3
Bldg. 485	94	79.8	114.6	149.5

Electrical and Thermal Interface. The electrical interface requirements for all three fuel cell energy systems were essentially the same. The fuel cell power plant was located close to the main distribution transformer in the case of the MFH unit cluster and close to the main electrical entrances of Buildings 416 and 485.

Commercial power from the electrical grid was connected to the fuel cell via a grid interconnect unit. This unit contained impedance matching and synchronizing circuits to make the fuel cell generated power compatible with the commercial grid, plus automatic switches to disconnect the fuel cell in case of failure or in case of a commercial power outage.

The estimated cost for the grid interconnect unit was based on a synchronizing unit for a diesel generator, plus the cost for a circuit breaker of appropriate size.

The fuel cell could be used to provide partial facility power in the case of a commercial power outage. However, to prevent overloading the fuel cell, only essential circuits, with a combined load not exceeding the KW rating of the fuel cell, could be connected.

The thermal interface requirements were also similar in configuration; however, the MFH unit cluster system required a more extensive underground hot water distribution system, plus a hot water holding tank. The two large facilities, on the other hand, required relatively short lengths of distribution piping, but needed water-to-air heat exchangers to reduce the return water temperature to the fuel cell.

The average size of piping required for each system was estimated using the gpm values calculated in Appendix D, and the estimated length of pipe required. These values were used in conjunction with a pipe sizing graph contained in the ASHARE Handbook [3:32].

Prices for the other interface components were picked to correspond as closely as possible with the KW, BTU and gpm ratings previously determined. For example, the flow rate of the water-to-water heat exchanger for Building 641 was calculated to be 5.4 gpm. The closest heat exchanger

size listed in the cost data used was a 7 gpm unit priced at $600. Therefore, this was the price used in the interface cost estimate. All prices listed in Table VII include materials and installation.

Table VII

Fuel Cell Electrical and Thermal Interface Cost

	MFH Unit Cluster	Building 641	Building 485
Electrical Service [14:224]	$690	$855	$2550
Grid Unit [14:177,315]	$787	$1215	$1567
Water-to-Water Heat Exchanger [15:179]	$350	$600	$1307
Water-to Air Heat Exchanger [15:181]	N/A	$342	$875
Circulating Pump(s) [15:145]	$478	$344	$435
3-Way Valve(s) [15:204]	$150	$422	$936
Storage Tank [15:183,196]	$1380	N/A	N/A
Hot Water Piping System [15:92,98,187]	$4192	$1204	$1617
Total Matls. & Labor	$8027	$4982	$9287

. . . . Table VII (Continued) . . . .

25 Percent Overhead & Profit [15:9]	$2007	$1246	$2322
Subtotal	$10034	$6228	$11609
15 Percent Design[15:7]	$1505	$934	$1741
Grand Total	$11539	$7162	$13350

Operations and Maintenance. The three O&M cost ranges listed in Table V are divided into two categories- fixed and variable. The fixed cost is static in that it is based on one finite value (i.e., 2.5 percent of fuel cell system cost or $15.33/KW of fuel cell size). The variable cost, on the other hand, depends on the operating time of the fuel cell system.

In order to determine the fixed cost factor of 2.5 percent of the fuel cell system cost, Bollenbacher's value for the fuel cell power plant installed cost ($1509/KW) was multiplied be each of the three fuel cell sizes previously determined. Each of these values was then added to the corresponding electrical and thermal interface cost for each installation listed in Table VII.

The annual KWH generated by each fuel cell was required to determine the variable cost. The number of hours of fuel cell power plant operation per year was based on a 97 percent operational reliability factor

(354 days/year or 8496 hours/yr) stated in Appendix E. Each fuel cell KW size was then multiplied by 8496 hours/yr to obtain the annual KWH power production. Table VIII lists the fixed and variable O&M costs for each fuel cell system.

Table VIII

Fixed and Variable O&M Costs

Fixed	MFH Unit Cluster	Bldg. 641	Bldg. 485
2.5% System Cost [5:Table V]	$465	$1,181	$3,778
$15.33/KWH [17:28]	$107	$429	$1,441
None [22:S-23]	$0	$0	$0
Variable			
$0.009/KWH [5:Table V]	$535	$2,141	$7,188
$0.021/KWH [17:28]	$1,249	$4,996	$16,771
$0.016/KWH [22:S-23]	$952	$3,806	$12,778

Thus, the total annual O&M cost for each fuel cell system ranged from $952 to 1,366 for the MFH unit cluster, $3,322 to 5,425 for Building 641, and $10,966 to $18,212 for Building 485.

Life-Cycle Cost Analysis

The life cycle cost analysis summaries for the three facilities studied are contained in Appendix G. The author found that none of the fuel cell energy systems was cost effective over the expected 25 year lifetime. All three systems did save energy initially (Item 2F3, Appendix G), but when the uniform present worth discount factors were applied, an overall life-cycle cost for energy was incurred instead of a savings.

Another significant factor in the life-cycle analysis that caused the fuel cell energy systems to show a net loss, was the O&M cost (Item 3A, Appendix G). Indeed, the O&M cost actually exceeded the initial cost of the fuel cell energy system in four out of the nine life-cycle cost analysis summaries. To illustrate the magnitude of the O&M cost, the life-cycle O&M cost values divided by the number of days in 25 years resulted in a daily O&M cost that ranged from a low of $1.22 per day for the MFH unit cluster system, to a high of $23.31 per day for Building 485. Perhaps even more realistic would be the daily cost range condensed into the 11 day downtime period previously estimated (i.e., 97 percent reliability or 354 day uptime per year). Within this 11 day period the daily O&M cost ranged from $40.33 per day to $770.25 per day.

One factor not included in the life-cycle cost analysis summaries was the reduction in KW demand that

would have resulted if each fuel cell was operated continuously at its maximum capacity. Operating at 100 percent capacity, without any downtime for maintenance or system failure, would ensure that the local electric utility company would measure a KW demand reduction identical to that of the rated KW of the fuel cell power plant. However, even if this ideal condition were met, the author determined that the savings in reduced KW demand charges amounted to only a five to nine percent reduction in the total non-energy savings cost (Item 3A, Appendix G). Therefore, KW demand reduction savings had no effect on the outcome of the life-cycle analysis summaries.

Using the total investment and the savings to investment ratio (SIR) values (Items 1F, and 6, Appendix G), a sensitivity analysis was then attempted to determine if the fuel cell energy systems proposed would be cost effective.

Sensitivity Analysis. The author's original intent in performing a sensitivity analysis was to develop a set of SIR's, three for each fuel cell energy system, and plot them on a graph versus the dollars per kilowatt ($/KW) installation cost similar to the graph shown in Figure 6. Since each point plotted would have been determined from a different set of installation and O&M costs, the curve produced by joining the points would have shown the sensitivity of the energy system to the combination of the

different sets of installation and O&M costs. It was also hoped that at least one of the energy systems would have an SIR of one or greater, indicating that that system was cost effective.

However, after the nine life-cycle analysis summaries were completed, all of the resulting SIR's were found to be negative. Because of this fact, it would have been pointless to attempt to plot any of the negative SIR values or, even if plotted, to extrapolate beyond the negative SIR points in an attempt to determine at what $/KW value the fuel cell energy system would be cost effective (i.e., have a breakeven cost). That is, conclusions concerning fuel cell energy system breakeven costs could not be drawn from such a graph because the negative numerator (savings) of the SIR could only become smaller (less negative in this analysis) if the denominator (cost of the energy system) of the SIR, increased. In other words, both the SIR and the $/KW values must be positive in order to produce a graph from which breakeven costs can be determined.

In spite of the negative SIR values, it may be of some use to future investigations to note that the average $/KW installed cost of the three systems studied were $2586/KW for the MFH unit cluster, $1330/KW for Building 641, and $1231/KW for Building 485. The relatively high $/KW value for the MFH unit cluster was due to the cost of the hot water distribution system to the eight MFH units.

V. Conclusions and Recommendations for Future Study

Conclusions

Although this thesis has shown that a fuel cell energy system, operated in a fixed power level mode, would not be cost effective for three, site specific installations, this does not mean that such systems would never be cost effective. As indicated in the life-cycle cost analysis, the two, main limiting factors in preventing achievement of a cost effective system were; first, the high cost of natural gas relative to that of electricity or coal derived steam; and second, the high cost of O&M for the energy system.

Assuming the life-cycle discount factors for the energy sources used in the cost analyses (electricity, natural gas, and coal derived steam) were reasonably accurate, then in order to increase the possibility of achieving an energy savings, the gas to electricity conversion efficiency of the fuel cell power plant must be improved and the thermal transfer capability of the fuel cell energy system needs to approach 100 percent.

Estimates of future fuel cell gas to electrical conversion efficiency range as high as 53 percent versus the 40 percent used in this study [17:30]. Therefore, a 50 percent conversion efficiency would not be unrealistic to expect in an actual installation. This efficiency equates

natural gas cost of each of the three proposed systems (Item 2D5, Appendix G).

In order to approach a 100 percent utilization of the fuel cell thermal output (especially the low grade thermal output) without costly facility HVAC system modifications, the energy system would have to be designed as part of a new HVAC system. This would mean the fuel cell energy system would need to be incorporated into the design of a new facility or HVAC system replacement in an existing facility due to a significant change in the heating or cooling loads (i.e., the installation of a large computer system, for instance).

Using the life-cycle cost analysis summary for Building 641 (Appendix G, page 71) as an example, and assuming that a major HVAC system replacement allowed for the use of 100 percent of the thermal energy from the fuel cell power plant, the amount of thermal energy transferred to the facility would increase from 315 MBTU/year to 900 MBTU/year. If the 10 percent reduction in natural gas required to operate the fuel cell was included as well, the life-cycle energy savings would change from -$40,831 to +$15,627. Although this would still not result in a SIR of plus one or greater, it does indicate that future fuel cell installations should be able to provide substantial energy savings.

The other main limiting factor, the O&M cost, appears to be too high especially when compared with the installed system cost. The annual O&M expenditure amounted to between seven and fifteen percent of the installed system cost. Using the previously cited life-cycle cost analysis summary for Building 641 and the seven percent uniform present worth factor (Appendix G, page 65), the cumulative, annual recurring O&M cost would exceed the system installed cost after only approximately 10 years. In light of this, the possibility of power plant replacement could be a means to reduce the high O&M cost, because a new unit should be less costly to maintain. At 10 years, again using a seven percent time value for money, the power plant replacement cost would be almost double the 1986 cost of $27,110; however, this replacement cost does not take into account the probable increased efficiency of the fuel cell power plant nor the reduced $/KW installed cost resulting from better design and a higher power plant production rate. However, because evaluation of the fuel cell as a commercially viable power system is continuing, it is not possible to state with certainty that future technological advances will significantly reduce O&M costs.

In conclusion, the findings of this thesis show that the life-cycle cost effectiveness of a fuel cell energy system, operated in a fixed power level mode, depends mainly on the cost of the power plant fuel (natural gas)

and the cost of O&M for the system. The initial installed cost of the system, on the other hand, had less impact on the outcome of the life-cycle cost effectiveness.

Recommendations for Future Study

The purpose of this thesis was to determine if a fuel cell energy system would be cost effective if installed at three facilities typical of the type located on WPAFB. While none of the proposed installations proved cost effective, future studies could be made using, or perhaps developing, different power plant sizing criteria. One advantage of a larger sized power plant that could be explored, for example, would be the cost effectiveness of selling fuel cell generated electric power back to the local commercial utility company during periods of low facility electrical demand.

Another area of possible research would be to perform life-cycle analyses on facilities on WPAFB or other bases that had more advantageous thermal to electric load ratios. Because this thesis was primarily concerned with facilities typical to WPAFB, the thermal to electric ratios of the three facilities chosen were not as high as they would be if the ratio was of primary importance to facility selection. In fact, the thermal to electric ratios for the three facilities studied were quite low. The ratios, determined by dividing the annual facility thermal consumption by the annual facility electrical consumption,

were; 0.26 for the MFH unit cluster, 0.20 for Building 641, and 1.20 for Building 485. If a study concentrated on facilities that could utilize most of the thermal energy of fuel cells that were sized to meet the total electrical loads, then the life-cycle SIR values might become one or greater even if the O&M costs remained high.

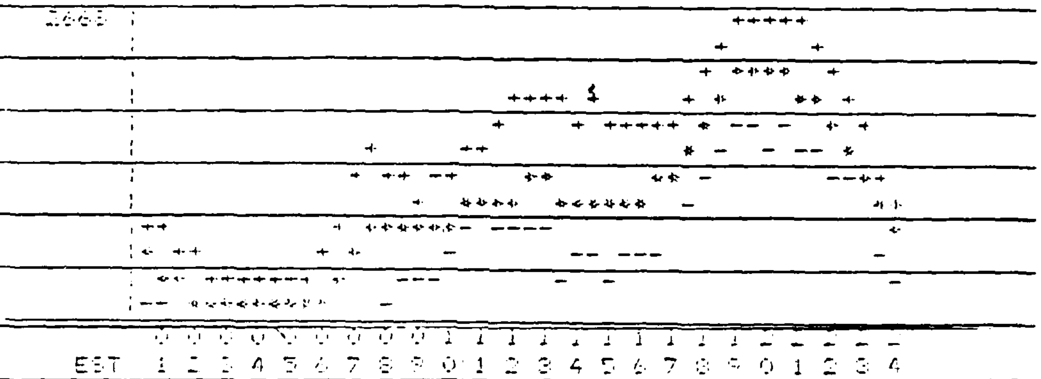
Instead of addressing facility sized fuel cell energy systems, a study of multi-megawatt sized systems could be pursued. These large systems would probably be integrated with existing, base operated heating plants. The thermal energy generated by these fuel cell power plants could be used to preheat the combustion air for the heating plant boilers. During the summer months, the thermal energy might have to be ejected into the atmosphere; however, the electrical generation efficiency of the fuel cell power plant would still be higher than the efficiency of a typical, coal fired, steam turbine generating plant of a local utility company.

Feasibility studies in these and other areas would be useful to DOD and USAF energy program and policy managers in making decisions concerning the installation of fuel cell energy systems. Such studies would provide more detailed information on energy system installations at specific bases and facilities using actual utility costs incurred by bases, as well as, more detailed electrical and thermal interface cost estimates.

Appendix A

Facility Electrical Energy Consumption Data

UPAFB	ENERGY USAGE SUMMARY	PAGE 1
01 FEB 86 02:05	PAGE MANOR MFH	
KEY: EB020445 00168	DEVICE: 44B DP&L W	DP&L KWD
01 JAN 86 THRU 31 JAN 86		



EST	-LOW	*AVG	+HIGH	EST	-LOW	*AVG	+HIGH
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01:30	1016	1212	1432	13:30	1306	1720	2204
02:00	952	1152	1394	14:00	1360	1702	2128
02:30	962	1130	1306	14:30	1394	1694	2150
03:00	950	1116	1296	15:00	1264	1676	2052
03:30	950	1104	1286	15:30	1372	1710	2084
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05:00	928	1096	1284	17:00	422	1768	2106
05:30	928	1118	1286	17:30	1642	1918	2204
06:00	950	1172	1394	18:00	1792	2060	2298
06:30	950	1308	1598	18:30	1966	2200	2516
07:00	982	1452	1826	19:00	2020	2268	2614
07:30	1026	1522	1900	19:30	2020	2288	2602
$\boxed{08:00}$	1124	$\boxed{1526}$	1824	$\boxed{20:00}$	1988	$\boxed{2294}$	2668
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09:30	1318	1556	1772	21:30	1890	2178	2474
10:00	1436	1594	1772	22:00	1826	2094	2386
10:30	1468	1634	1868	22:30	1738	1976	2246
11:00	432	1618	1976	23:00	1058	1814	2062
11:30	1490	1712	2128	23:30	1404	1644	1814
$\boxed{12:00}$	1512	$\boxed{1720}$	2150	$\boxed{24:00}$	1318	$\boxed{1478}$	1630

-LOWEST-		+HIGHEST+	
02 JAN 86 17:00	422	27 JAN 86 20:00	2668
23 JAN 86 11:00	432	05 JAN 86 20:30	2624
13 JAN 86 05:00	928	05 JAN 86 19:00	2614

TOTAL DP&L KWH: 1206642 AVERAGE DP&L KWD: 1638

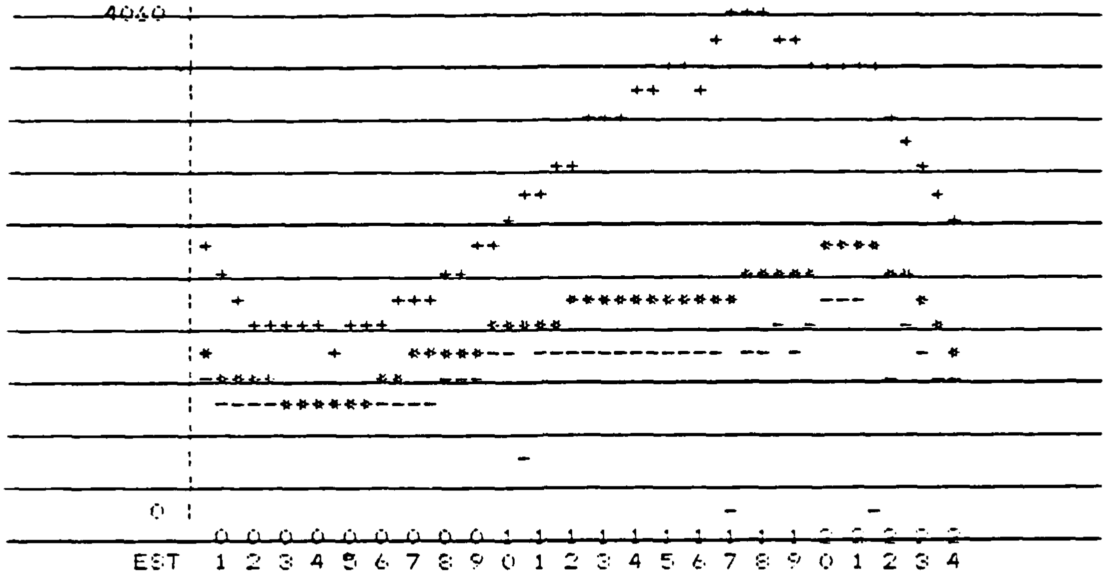
WPAFB ENERGY USAGE SUMMARY PAGE 1

01 MAY 86 02:05

PAGE MANOR MFH

KEY: ER02044B 00163 DEVICE: 44E DEM W DEM KW

01 APR 86 THRU 30 APR 86



EST	-LOW	*AVG	+HIGH	EST	-LOW	*AVG	+HIGH
00:30	1026	1258	2062	12:30	1252	1640	3056
01:00	950	1158	1836	13:00	1242	1634	3142
01:30	925	1092	1716	13:30	1232	1644	3240
02:00	874	1050	1620	14:00	1274	1652	3370
02:30	864	1014	1574	14:30	1242	1654	3412
03:00	854	996	1502	15:00	1252	1690	3574
03:30	842	974	1424	15:30	1232	1718	3440
04:00	842	964	1426	16:00	1306	1676	3348
04:30	832	950	1360	16:30	1328	1718	3812
05:00	842	966	1426	17:00	0	1796	3996
05:30	854	983	1566	17:30	1360	1900	4040
06:00	864	1064	1610	18:00	1360	1918	4060
06:30	886	1142	1664	18:30	1448	1942	3844
07:00	874	1244	1652	19:00	1414	1976	3704
07:30	940	1280	1718	19:30	1546	2016	3516
08:00	1058	1310	1836	20:00	1738	2114	3520
08:30	1154	1334	1944	20:30	1750	2186	3596
09:00	1210	1384	2138	21:00	1782	2182	3628
09:30	1230	1450	2170	21:30	0	2050	3532
10:00	1296	1508	2258	22:00	1210	2012	3186
10:30	404	1522	2526	22:30	1576	1894	3002
11:00	1306	1574	2592	23:00	1328	1718	2764
11:30	1304	1404	2744	23:30	1196	1530	2526
12:00	1306	1626	2830	24:00	1080	1370	2278

-LOWEST-		+HIGHEST+	
11 APR 86 21:30	0	27 APR 86 18:00	4060
22 APR 86 17:00	0	27 APR 86 17:30	4040
18 APR 86 10:30	404	27 APR 86 17:00	3996

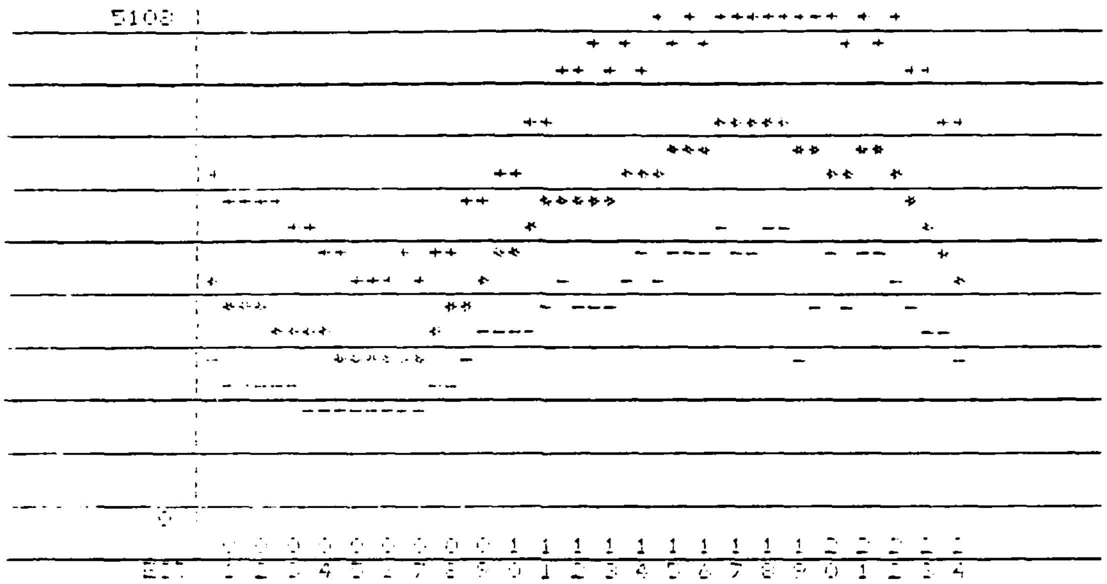
TOTAL DEM KWH: 1094204 AVERAGE DEM KWD: 1536

..AFB ENERGY USAGE SUMMARY PAGE 1
01 AUG 85 12:04

PAGE MANOR MFH

ID: EB020485 00100 DEVICE: 44B DFSL W DFSL KW

01 JUL 85 THRU 31 JUL 85



EST	-LOW	+AVG	+HIGH	EST	-LOW	+AVG	+HIGH
00:30	1602	2271	2564	12:30	2224	3308	4806
01:00	1470	2254	2316	13:00	2290	3318	4552
01:30	1311	2160	2284	13:30	2398	3364	4752
02:00	[illegible]	[illegible]	3110	14:00	2602	3436	4566
02:30	1250	1953	3078	14:30	2548	3508	4914
03:00	1276	1874	2362	15:00	2764	3606	4682
03:30	1264	1826	2924	15:30	2678	3704	4904
04:00	1222	1788	2732	16:00	2732	3828	4698
04:30	1212	1752	2774	16:30	2818	3922	4934
05:00	1242	1736	2516	17:00	2808	3974	5082
05:30	1193	1742	2548	17:30	2798	3976	5066
06:00	1188	1758	2528	18:00	2830	3948	5108
06:30	1188	1741	2570	18:30	2884	3864	5084
07:00	1242	1772	2454	19:00	1642	3698	5000
07:30	1414	1914	2786	19:30	2128	3636	4946
08:00	1512	2044	2786	20:00	2624	3572	4924
08:30	1620	2212	3196	20:30	2290	3496	4774
09:00	1822	2426	3110	21:00	2560	3586	4924
09:30	1852	2572	3358	21:30	2582	3592	4742
10:00	1934	2772	3552	22:00	2298	3482	4892
10:30	1974	2963	4004	22:30	2278	3228	4580
11:00	2100	3074	3756	23:00	1988	2976	4450
11:30	2300	3212	4374	23:30	1868	2724	3920
12:00	2214	3258	4352	24:00	1664	2544	3856

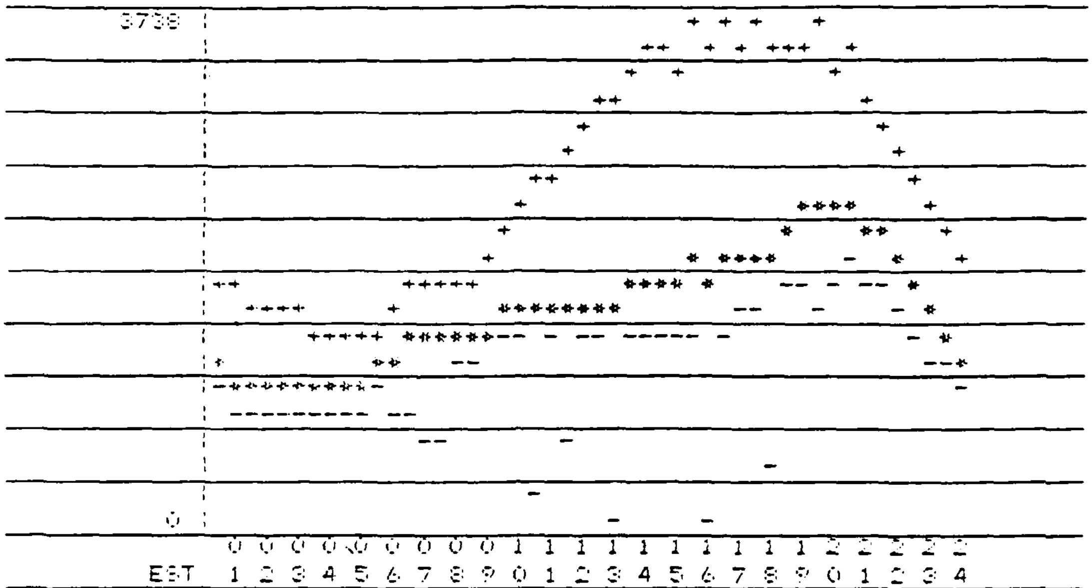
-LOWEST-		+HIGHEST+	
07 JUL 85 06:00	1188	14 JUL 85 18:00	5108
07 JUL 85 06:30	1188	14 JUL 85 18:30	5088
07 JUL 85 05:30	1198	14 JUL 85 17:30	5066

TOTAL DFSL KWH: 2130105 AVERAGE DFSL KWD: 2866

WPAFB ENERGY USAGE SUMMARY PAGE 2
01 NOV 85 02:05 PAGE MANOR MFH

KEY: EB02044B 00168 DEVICE: 44B DF&L W
KEY: EB02044B 00167 DEVICE: 44B DF&L Q KVA

01 OCT 85 THRU 31 OCT 85



EST	-LOW	*AVG	+HIGH	EST	-LOW	*AVG	+HIGH
00:30	974	1174	1836	12:30	1392	1680	3044
01:00	932	1106	1768	13:00	68	1624	3176
01:30	922	1074	1638	13:30	1326	1712	3336
02:00	888	1044	1626	14:00	1322	1756	3378
02:30	888	1020	1552	14:30	1330	1790	3456
03:00	882	1008	1528	15:00	1352	1828	3308
03:30	852	988	1452	15:30	1390	1894	3574
04:00	872	990	1424	16:00	0	1856	3444
04:30	874	992	1358	16:30	1480	1994	3738
05:00	882	1036	1408	17:00	1570	2000	3480
05:30	942	1148	1458	17:30	1640	2040	3662
06:00	932	1266	1640	18:00	446	2038	3544
06:30	934	1384	1722	18:30	1738	2152	3530
07:00	710	1400	1736	19:00	1726	2246	3440
07:30	656	1396	1744	19:30	1532	2280	3594
08:00	1164	1434	1766	20:00	1848	2310	3358
08:30	1280	1452	1816	20:30	1906	2282	3374
09:00	1338	1486	2008	21:00	1856	2198	3118
09:30	1362	1548	2108	21:30	1776	2078	2898
10:00	1362	1570	2292	22:00	1618	1912	2718
10:30	312	1570	2502	22:30	1488	1730	2478
11:00	1412	1646	2568	23:00	1286	1534	2302
11:30	734	1636	2788	23:30	1128	1378	2148
12:00	1416	1646	2934	24:00	1028	1268	2006

-LOWEST-		+HIGHEST+	
02 OCT 85 16:00	0	13 OCT 85 16:30	3738
06 OCT 85 13:00	68	13 OCT 85 17:30	3662
17 OCT 85 10:30	312	13 OCT 85 19:30	3594

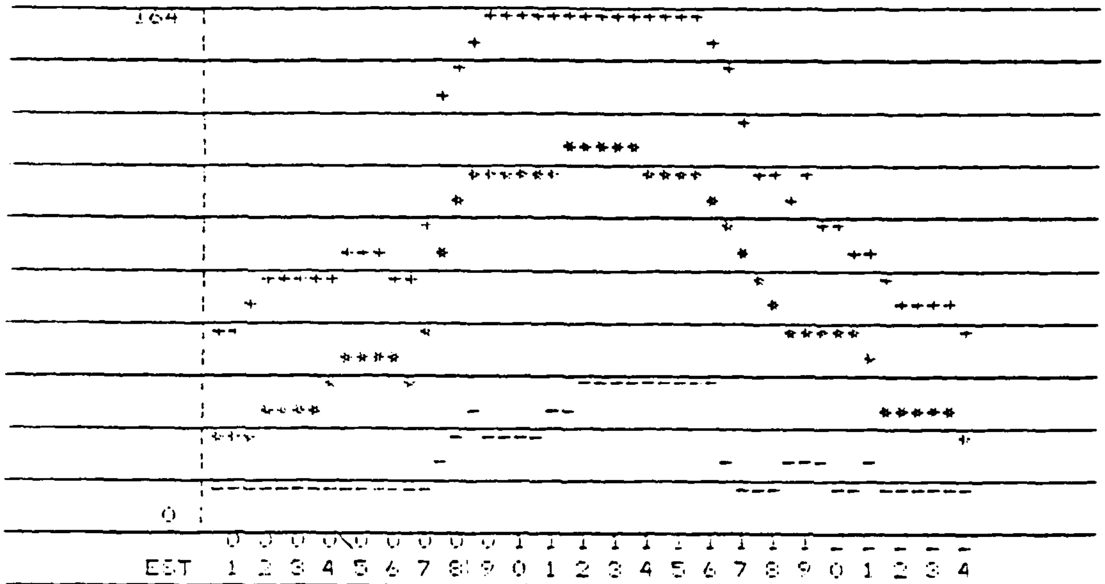
TOTAL KVAH: 991233 AVERAGE KVA: 1598

01 FEB 86 11:10

BUILDING 641

KEY: EB020641 00280 DEVICE: PG641-1 SW-GR BLDG KWD

01 JAN 86 THRU 31 JAN 86



EST	-LOW	*AVG	+HIGH	EST	-LOW	*AVG	+HIGH
00:30	12	32	62	12:30	46	116	160
01:00	12	32	62	13:00	44	116	162
01:30	14	[illegible]	70	13:30	46	116	160
02:00	14	34	76	14:00	46	114	160
02:30	14	36	76	14:30	46	114	158
03:00	14	36	80	15:00	46	114	160
03:30	16	40	76	15:30	44	[illegible]	156
04:00	14	42	78	16:00	42	106	152
04:30	14	52	88	16:30	[illegible]	96	140
05:00	14	54	86	17:00	14	86	130
05:30	12	52	86	17:30	12	74	114
06:00	16	50	80	18:00	14	66	110
06:30	14	48	76	18:30	18	64	102
07:00	12	58	96	19:00	18	62	108
07:30	22	82	132	19:30	18	60	98
08:00	32	104	144	20:00	16	60	96
08:30	36	110	154	20:30	16	58	86
09:00	26	110	158	21:00	18	56	84
09:30	26	110	158	21:30	16	40	76
10:00	32	112	158	22:00	16	38	68
10:30	28	114	162	22:30	14	36	68
11:00	36	112	158	23:00	16	34	68
11:30	36	118	160	23:30	14	34	66
12:00	44	118	164	24:00	14	32	64

-LOWEST-		+HIGHEST+	
13 JAN 86 01:00	12	30 JAN 86 12:00	164
19 JAN 86 17:30	12	30 JAN 86 10:30	162
20 JAN 86 05:30	12	30 JAN 86 13:00	162

TOTAL BLDG KWH: 53940 AVERAGE BLDG KWD: 74

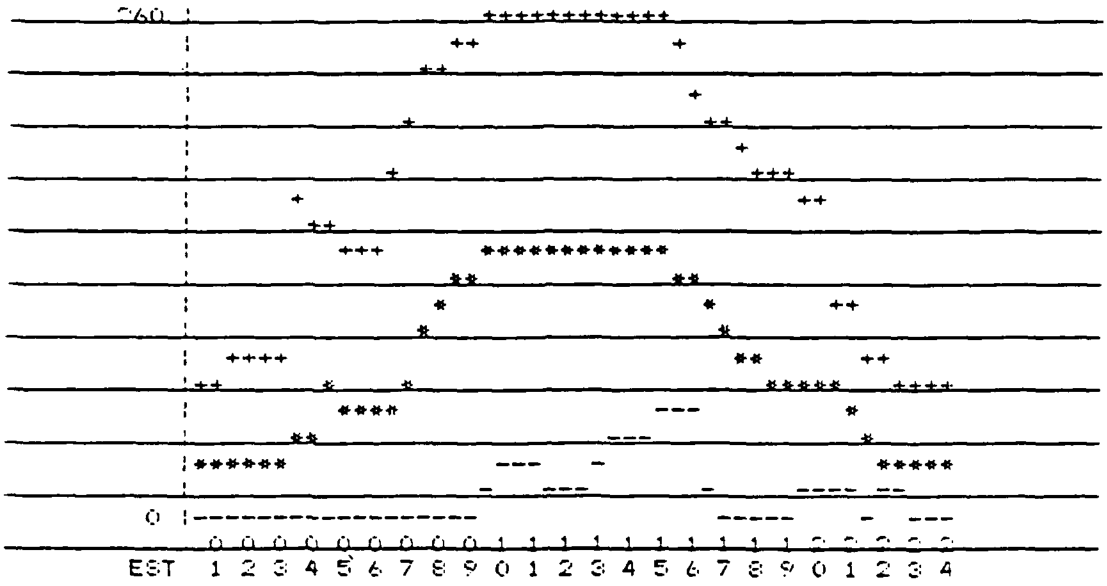
WPAFB ENERGY USAGE SUMMARY PAGE 19

01 MAY 86 09:29

BUILDING 641

KEY: EB020641 00260 DEVICE: EG641-1 SW-GR BLDG KWD

01 APR 86 THRU 30 APR 86



EST	-LOW	*AVG	+HIGH	EST	-LOW	*AVG	+HIGH
00:30	12	28	68	12:30	18	132	252
01:00	12	30	68	13:00	28	132	254
01:30	10	32	80	13:30	50	132	254
02:00	12	32	78	14:00	50	134	252
02:30	10	34	78	14:30	50	132	248
03:00	10	34	82	15:00	52	132	252
03:30	10	40	154	15:30	54	128	[illegible]
04:00	10	44	154	16:00	52	122	220
04:30	10	[illegible]	144	16:30	16	[illegible]	204
05:00	10	64	140	17:00	0	94	196
05:30	10	62	136	17:30	12	84	180
06:00	10	58	142	18:00	12	78	176
06:30	6	54	178	18:30	12	72	178
07:00	6	68	206	19:00	10	68	172
07:30	10	92	224	19:30	16	70	164
08:00	10	116	232	20:00	14	74	164
08:30	12	122	238	20:30	14	68	110
09:00	12	128	246	21:00	16	64	106
09:30	20	130	254	21:30	12	42	88
10:00	26	132	248	22:00	14	38	78
10:30	26	130	248	22:30	16	34	76
11:00	28	132	256	23:00	12	34	74
11:30	20	132	254	23:30	12	32	70
12:00	18	132	260	24:00	12	30	70

-LOWEST-		+HIGHEST+	
22 APR 86 17:00	0	30 APR 86 12:00	260
12 APR 86 06:30	6	30 APR 86 09:30	256
12 APR 86 07:00	6	30 APR 86 11:00	256

TOTAL BLDG KWH: 59584 AVERAGE BLDG KWD: 84

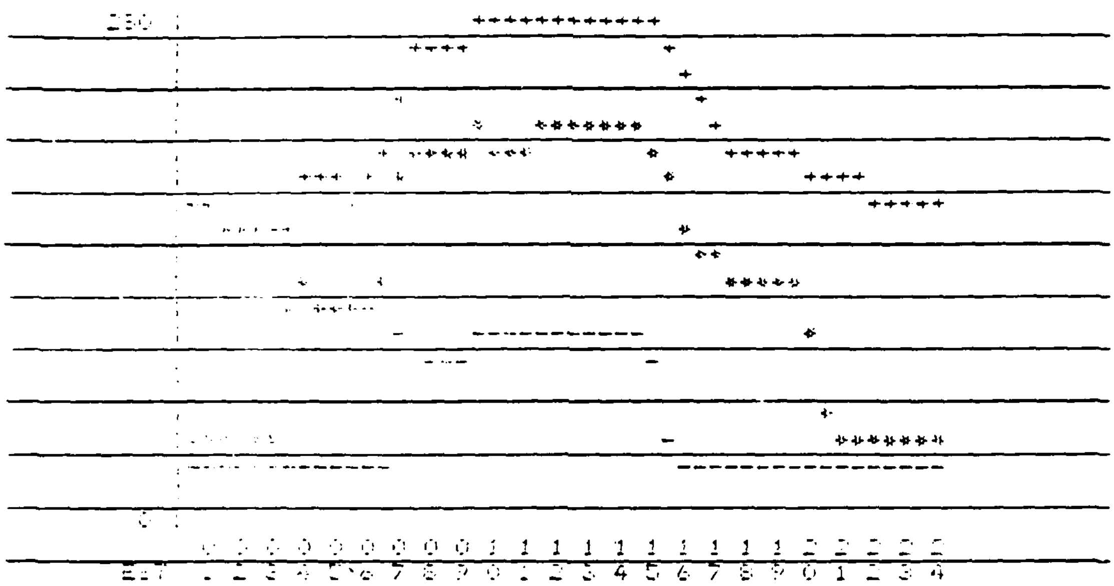
[illegible]AFB ENERGY USAGE SUMMARY PAGE 15

01 AUG 85 14:10

BUILDING 641

[illegible] 00200 DEVICE: PG641-1 SW-GR BLDG KWD

01 JUL 85 THRU 31 JUL 85



EST	-LOW	*AVG	+HIGH	EST	-LOW	*AVG	+HIGH
00:30	36	[illegible]	174	12:30	102	214	274
01:00	36	54	174	13:00	108	216	272
01:30	36	54	[illegible]	13:30	104	216	274
02:00	36	[illegible]	[illegible]	14:00	104	216	280
02:30	36	54	158	14:30	102	212	274
03:00	36	54	160	15:00	84	200	270
03:30	36	112	152	15:30	44	190	260
04:00	36	130	[illegible]	16:00	40	166	242
04:30	38	[illegible]	[illegible]	16:30	36	150	228
05:00	36	[illegible]	[illegible]	17:00	36	140	214
05:30	36	112	172	17:30	34	132	206
06:00	32	114	184	18:00	36	130	202
06:30	36	[illegible]	208	18:30	36	128	202
07:00	108	[illegible]	236	19:00	36	126	200
07:30	96	[illegible]	254	19:30	36	128	198
08:00	96	204	[illegible]	20:00	36	106	188
08:30	96	202	264	20:30	36	58	182
09:00	94	208	264	21:00	40	54	182
09:30	98	210	270	21:30	40	54	182
10:00	96	208	272	22:00	40	52	178
10:30	100	208	272	22:30	38	52	178
11:00	104	202	270	23:00	36	52	174
11:30	106	212	274	23:30	36	50	172
12:00	104	214	272	24:00	38	52	168

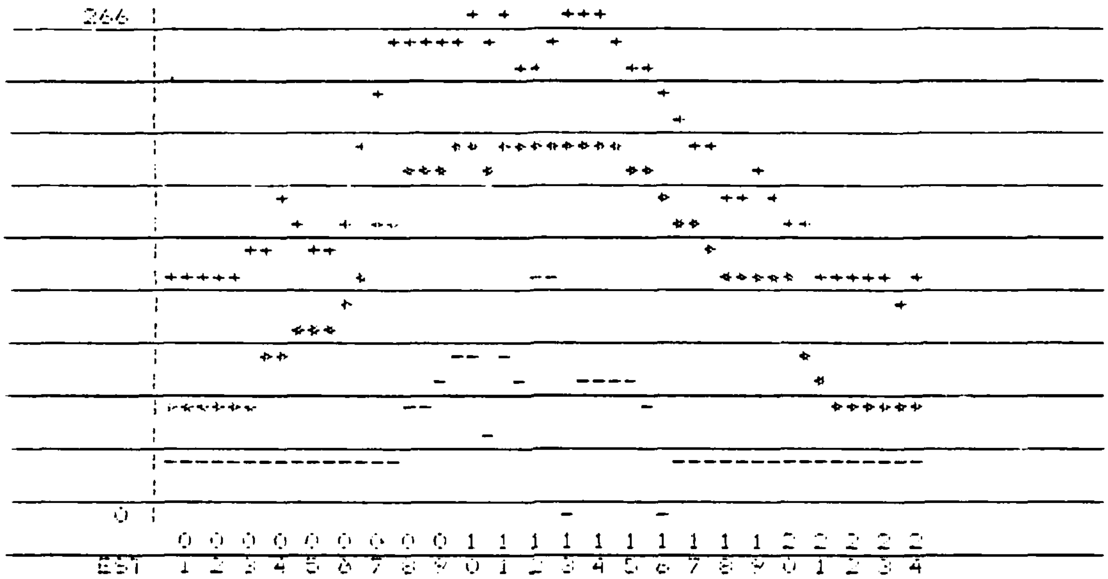
-LOWEST-		+HIGHEST+	
17 JUL 85 06:00	32	08 JUL 85 14:00	280
[illegible] JUL 85 06:00	32	15 JUL 85 13:00	278
[illegible] JUL 85 06:00	34	15 JUL 85 14:00	278

TOTAL BLDG KWH: 100606 AVERAGE BLDG KWD: 136

BUILDING 641

KEY: EB020641 00260 DEVICE: PG641-1 SW-GR BLDG KWD

01 OCT 85 THRU 31 OCT 85



EST	-LOW	*AVG	+HIGH	EST	-LOW	*AVG	+HIGH
00:30	34	58	122	12:30	124	198	252
01:00	30	58	124	13:00	2	192	266
01:30	34	60	124	13:30	68	194	258
02:00	30	62	128	14:00	70	194	254
02:30	32	64	132	14:30	70	190	240
03:00	34	66	134	15:00	74	186	236
03:30	32	90	140	15:30	62	176	232
04:00	36	92	142	16:00	0	160	216
04:30	30	102	150	16:30	36	156	212
05:00	32	102	146	17:00	36	148	198
05:30	32	100	142	17:30	36	136	188
06:00	32	108	154	18:00	36	132	172
06:30	32	130	190	18:30	36	132	170
07:00	32	152	218	19:00	36	132	174
07:30	38	158	240	19:30	36	125	164
08:00	64	176	246	20:00	36	120	154
08:30	62	180	240	20:30	36	84	150
09:00	68	182	250	21:00	34	76	126
09:30	80	188	250	21:30	34	64	126
10:00	84	190	254	22:00	34	62	126
10:30	48	184	232	22:30	34	60	122
11:00	80	172	260	23:00	34	58	122
11:30	72	190	238	23:30	34	58	118
12:00	124	196	238	24:00	32	56	130

-LOWEST-		+HIGHEST+	
[illegible] OCT 85 16:00	0	24 OCT 85 13:00	266
[illegible] OCT 85 13:00	2	24 OCT 85 11:00	260
[illegible] OCT 85 04:30	30	24 OCT 85 13:30	258

TOTAL BLDG KWH: 80341 AVERAGE BLDG KWD: 130

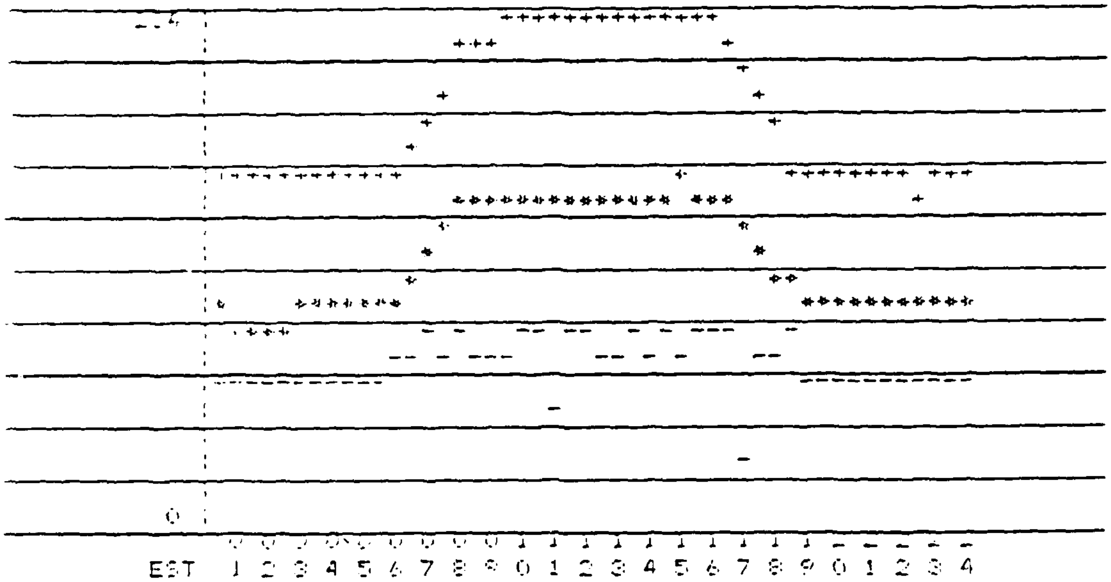
WRAFB ENERGY USAGE SUMMARY PAGE 16

01 FEB 86 10:30

BUILDING 485

KEY: EB020450 00266 DEVICE: FG485-1 1000KVA BLDG KWD

01 JAN 86 THRU 31 JAN 86



EST	-LOW	*AVG	+HIGH	EST	-LOW	*AVG	+HIGH
00:30	68	94	156	12:30	80	150	230
01:00	64	92	156	13:00	78	150	226
01:30	[illegible]	92	160	13:30	82	152	234
02:00	66	92	156	14:00	80	152	232
02:30	66	92	156	14:30	82	152	228
03:00	66	94	158	15:00	80	154	224
03:30	66	92	156	15:30	82	152	228
04:00	68	96	160	16:00	84	150	226
04:30	66	96	160	16:30	82	144	216
05:00	70	96	156	17:00	34	132	206
05:30	68	96	162	17:30	80	124	188
06:00	72	98	160	18:00	80	112	176
06:30	80	106	168	18:30	82	106	160
07:00	82	120	186	19:00	66	104	162
07:30	78	[illegible]	194	19:30	66	102	156
08:00	84	142	212	20:00	70	100	156
08:30	80	146	218	20:30	70	100	156
09:00	80	148	222	21:00	68	98	158
09:30	78	150	228	21:30	70	96	156
10:00	84	150	224	22:00	62	94	160
10:30	82	152	226	22:30	64	94	152
11:00	48	146	228	23:00	66	94	158
11:30	84	152	226	23:30	60	94	156
12:00	82	150	228	24:00	64	94	158

-LOWEST-		+HIGHEST+	
02 JAN 86 17:00	34	06 JAN 86 13:30	234
23 JAN 86 11:00	48	06 JAN 86 14:00	232
30 JAN 86 23:30	60	06 JAN 86 12:30	230

TOTAL BLDG KWH: 88834 AVERAGE BLDG KWD: 120

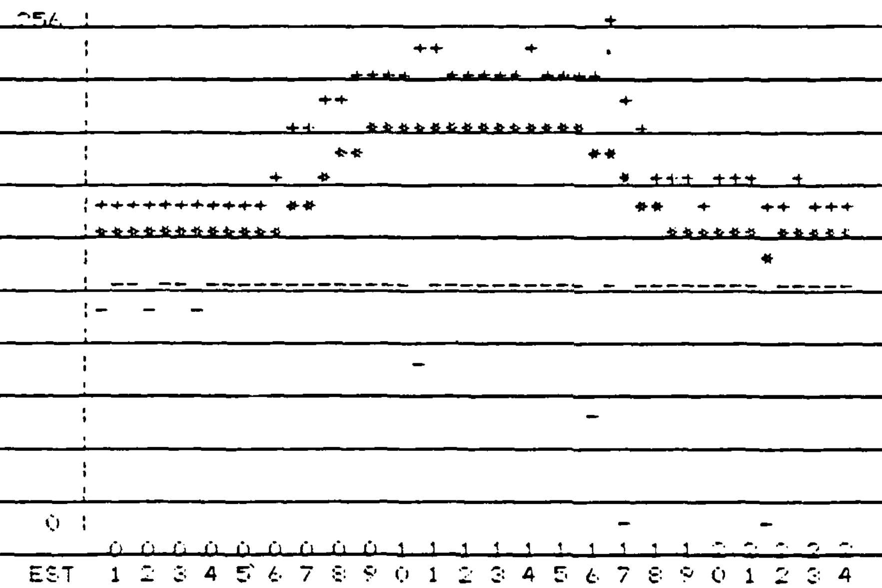
WPAFB ENERGY USAGE SUMMARY PAGE 16

01 MAY 86 09:10

BUILDING 485

KEY: EB020485 00266 DEVICE: PG485-1 1000KVA BLDG KWD

01 APR 86 THRU 30 APR 86



EST	-LOW	*AVG	+HIGH	EST	-LOW	*AVG	+HIGH
00:30	114	144	166	12:30	120	194	226
01:00	118	144	162	13:00	120	194	226
01:30	120	144	166	13:30	120	196	226
02:00	114	142	164	14:00	118	196	232
02:30	116	142	162	14:30	120	196	226
03:00	120	142	164	15:00	120	196	228
03:30	114	142	160	15:30	118	194	226
04:00	118	144	162	16:00	60	186	224
04:30	118	146	164	16:30	118	186	254
05:00	118	144	162	17:00	0	168	208
05:30	116	144	166	17:30	118	162	192
06:00	116	146	176	18:00	118	156	174
06:30	118	154	200	18:30	120	152	172
07:00	120	166	204	19:00	116	150	170
07:30	116	174	210	19:30	120	148	164
08:00	122	184	216	20:00	116	148	168
08:30	120	188	218	20:30	120	148	168
09:00	120	192	224	21:00	120	146	168
09:30	120	194	230	21:30	0	138	164
10:00	120	196	228	22:00	120	146	164
10:30	88	194	232	22:30	118	146	168
11:00	120	198	232	23:00	116	146	164
11:30	116	196	228	23:30	116	146	166
12:00	120	196	226	24:00	118	144	166

-LOWEST-		+HIGHEST+	
11 APR 86 21:30	0	22 APR 86 16:30	254
22 APR 86 17:00	0	08 APR 86 14:00	232
27 APR 86 16:00	60	22 APR 86 14:00	232

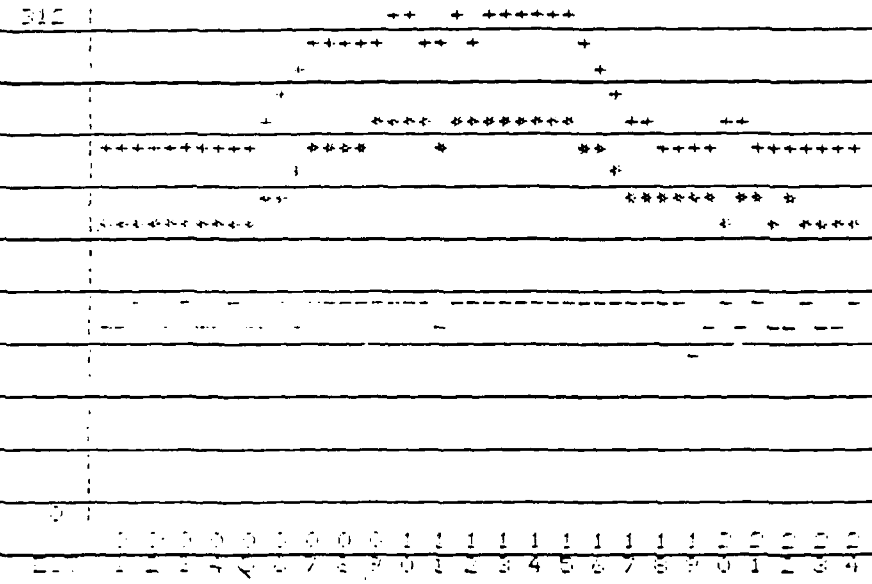
TOTAL BLDG KWH: 119036 AVERAGE BLDG KWD: 166

[illegible] ENERGY USAGE SUMMARY PAGE [illegible]
[illegible] AUG 85 13:50

BUILDING485

[illegible] 00[illegible] DEVICE: PS485-1 1000KVA BLDG KWD

[illegible] JUL 85 THRU 31 JUL 85



EST	-LOW	*AVG	+HIGH	EST	-LOW	*AVG	+HIGH
00:30	122	182	230	12:30	130	240	312
01:00	124	173	224	13:00	128	242	304
01:30	122	173	224	13:30	130	240	300
02:00	[illegible]	[illegible]	[illegible]	14:00	128	242	304
02:30	124	174	232	14:30	134	240	298
03:00	122	171	226	15:00	130	238	298
03:30	122	17[illegible]	224	15:30	132	232	292
04:00	124	176	226	16:00	134	224	272
04:30	122	171	232	16:30	126	210	264
05:00	122	[illegible]	222	17:00	128	200	240
05:30	124	183	244	17:30	128	196	236
06:00	130	172	250	18:00	130	192	230
06:30	122	210	270	18:30	132	192	224
07:00	122	220	290	19:00	102	188	232
07:30	126	228	284	19:30	120	188	228
08:00	126	230	290	20:00	130	186	234
08:30	132	230	296	20:30	124	190	236
09:00	128	234	294	21:00	130	188	226
09:30	126	236	304	21:30	124	186	228
10:00	132	234	302	22:00	124	188	230
10:30	128	236	294	22:30	126	186	230
11:00	124	232	294	23:00	124	180	226
11:30	130	234	308	23:30	124	186	230
12:00	128	234	294	24:00	128	182	226

-LOWEST-		+HIGHEST+	
2[illegible] JUL 85 19:00	102	30 JUL 85 12:30	312
[illegible] JUL 85 19:30	120	31 JUL 85 11:30	308
26 JUL 85 02:30	120	25 JUL 85 11:30	304

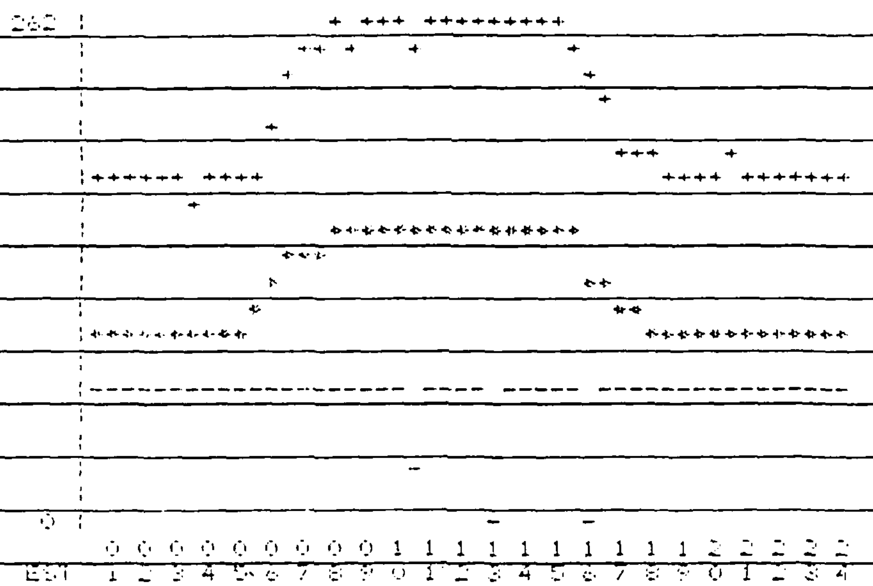
TOTAL BLDG KWH: 153174 AVERAGE BLDG KWD: 206

WPAFB ENERGY USAGE SUMMARY PAGE 14

01 NOV 85 07:49 BUILDING 485

KEY: EB020485 00266 DEVICE: PG485-1 1000KVA BLDG KWD

01 OCT 85 THRU 31 OCT 85



EST	-LOW	*AVG	+HIGH	EST	-LOW	*AVG	+HIGH
00:30	68	98	174	12:30	76	156	258
01:00	68	100	176	13:00	4	150	262
01:30	74	100	100	13:30	74	154	262
02:00	72	100	178	14:00	74	152	258
02:30	74	100	178	14:30	78	152	258
03:00	74	98	176	15:00	78	150	250
03:30	70	98	170	15:30	76	146	240
04:00	74	100	178	16:00	0	130	230
04:30	74	102	178	16:30	76	126	214
05:00	74	102	178	17:00	74	114	190
05:30	74	108	178	17:30	78	108	190
06:00	74	118	204	18:00	76	102	184
06:30	76	136	228	18:30	76	102	182
07:00	74	136	238	19:00	78	102	182
07:30	66	140	240	19:30	74	102	182
08:00	74	150	252	20:00	74	102	182
08:30	74	150	244	20:30	70	100	186
09:00	76	152	250	21:00	72	100	180
09:30	76	154	250	21:30	72	98	178
10:00	74	154	254	22:00	74	98	174
10:30	34	148	246	22:30	74	98	176
11:00	74	154	254	23:00	74	98	178
11:30	76	150	254	23:30	70	96	174
12:00	78	154	254	24:00	66	96	172

-LOWEST-		+HIGHEST+	
02 OCT 85 16:00	0	01 OCT 85 13:00	262
06 OCT 85 13:00	4	01 OCT 85 13:30	262
17 OCT 85 10:30	34	01 OCT 85 12:30	258

TOTAL BLDG KWH: 75920 AVERAGE BLDG KWD: 122

Appendix B

Estimation of MFH Unit Cluster Hot Water Requirements

Average occupancy per MFH unit cluster(8 units): 24

Gallons of 140 degree hot water required per day:[23:B200]

20 gal/person for first 16 persons =	320 gal
5 gal/person for remaining 8 persons =	40 gal
20 gal for each automatic washer =	160 gal
Total	520 gal/day

Average Ground Water Temperature: 52°F [11:C-48]

Gas Water Heater Efficiency: 0.75 [23:B200]

Daily Hot Water Thermal Requirement:

$$\frac{520 \text{ gal/day} \times 8.25 \text{ BTU/gal-}^{\circ}\text{F} \times (140^{\circ}\text{F} - 52 \text{ F})}{0.75}$$

$$= 503{,}360 \text{ BTU/day [23:B203]}$$

Annual Thermal Requirement:

$$\frac{503{,}360 \text{ BTU/day} \times 365 \text{ days/year}}{1000 \text{ BTU/KBTU}} = 183{,}726 \text{ KBTU/year}$$

Fuel Cell to MFH Unit Cluster Hot Water Distribution Heat Loss:

Approximately 400 linear feet of insulated pipe (average diameter of one inch) was required to distribute the fuel cell generated hot water to 8 MFH units. The heat loss was estimated to be 10 BTU/foot/hour [11:H1a]. Therefore, the annual heat loss was:

$$\frac{10 \text{ BTU/foot/hour} \times 8760 \text{ hours/year} \times 400 \text{ feet of pipe}}{1000\text{BTU/KBTU}}$$

$$= 35{,}020 \text{ KBTU/year}$$

Central Hot Water Storage Tank Heat Loss:

Assuming 500 gal storage tank size with 3 inches of insulation, the estimated heat loss is 8,400 KBTU/year [10:134]

Total Annual MFH Unit Cluster Thermal Requirement:

Hot Water	183,726	KBTU/year
Distribution Heat Loss	35,040	
Storage Tank Heat Loss	8,400	
Total Annual Heat Requirement	277,166	KBTU/year

(Listed in Table II as 18,930 KBTU/month)

Appendix C

Fuel Cell Power Plant Sizing and Thermal Output Calculations

To determine the size of the fuel cell power plant for each facility, the first two sizing constraints were used initially to obtain an approximate power plant KW size. Then the thermal output of the power plant was estimated using ratio multipliers based on the rated thermal output of an operational 40 KW power plant described in Taylor's report, namely, 150,000 BTU/hour or 1,314,000 KBTU/year [20:423].

The ratio multiplier was determined by dividing the power plant estimated annual thermal output into the annual facility thermal requirement. This ratio multiplier was then used to adjust the approximate power plant KW size.

For example, assume the first two sizing constraints indicated that a 50 KW power plant would be practical. If the annual thermal load of a facility was 1,500,000 KBTU/year, the thermal output constraint would require the power plant size be adjusted by the following method.

50 KW power plant thermal output:

$$1{,}314{,}000 \text{ KBTU/year} \times \frac{50\text{KW}}{40\text{KW}} = 1{,}642{,}500 \text{ KBTU/year}$$

Size adjustment due to lower facility thermal requirement:

$$\frac{1{,}500{,}000 \text{ KBTU/year(facility requirement)}}{1{,}642{,}500 \text{ KBTU/year(fuel cell output)}} \times 50 \text{ KW} = 45 \text{ KW}$$

The adjusted fuel cell power plant sizes for the three facilities studied are shown in Table IX.

Table IX

Fuel Cell Power Plant Size Adjustment

Facility	Ratio Multiplier	Approx. Size	Thermally Adj. Size
MFH Unit Cluster	227,166 KBTU/year / 262,800 KBTU/year	8 KW	7 KW
Bldg. 641	590,612 KBTU/year / 2,759,400 KBTU/year	84 KW	18 KW
Bldg. 485	5,513,084 KBTU/year / 3,087,900 KBTU/year	94 KW	168 KW

Note that the adjusted power plant sizes for Buildings 641 and 485 were not within the 10 and 30 percent boundaries of the first sizing constraint. In these cases, the power plant sizes chosen were the lower boundary limit of 28 KW for Building 641 and the upper boundary limit of 94 KW for Building 485. The author considered the first sizing constraint of primary importance because it was based on actual unit costs for electrical and thermal energy at WPAFB. Thefore, the first sizing constraint was observed in all three sizing determinations.

The size adjusted fuel cell power plant thermal outputs for the KW sizes chosen were determined as previously shown in this appendix. Table X shows the final fuel cell sizes and their corresponding thermal output.

Table X

Final Fuel Cell Power Plant Size and Thermal Output

Facility	Fuel Cell Size	Thermal Output
MFH Unit Cluster	7 KW	26,250 BTU/hr
Bldg. 641	28 KW	105,000 BTU/hr
Bldg. 485	94 KW	352,500 BTU/hr

Appendix D

Fuel Cell Energy System Thermal Energy Transfer Calculations

The gallon per minute (gpm) of hot water flow to the fuel cell heat exchangers required to transfer the fuel cell generated thermal energy was determined from the BTU/hour output rating of the fuel cell power plant and the temperature difference between the supply and return water required by the facility heat exchanger to provide the required temperature rise to water in the facility heating system. Figure 16 is a sizing chart from a heat exchanger manufacturer and shows the temperature of the supply (heating) water required to obtain a certain temperature rise in the facility (heated) water. Note that the maximum heating water temperature drop possible was chosen in order to reduce the temperature of the return heating water back to the fuel cell heat exchanger(s).

The temperature values indicated in Figure 16 were used in the following formula to produce the gpm values shown in Table XI. The formula used to calculate the gpm values is shown below:

$$\text{GPM} = \frac{\text{BTU/hr}}{\text{Fac. Temp. Change F} \times 8.33^{*}\ \text{Btu/gal-}^{\circ}\text{F} \times 60\ \text{min/hr}} \quad [4:6]$$

* BTU/hr factor varies with average facility water temperature.

		230° HEATING WATER											
Heated Water		TEMPERATURE DROP											
In	Out	5°	10°	15°	20°	30°	40°	50°	60°	70°	80°	90°	100°
40	60	4.25	4.33	4.41	4.50	4.68	4.88	5.10	5.34	5.61	5.92	6.26	6.65
	80	8.90	9.07	9.26	9.45	9.85	10.30	10.79	11.34	11.96	12.66	13.47	14.42
	100	14.09	14.38	14.69	15.00	15.69	16.46	17.31	18.27	19.38	20.65	22.16	23.97
	120	20.02	20.47	20.94	21.43	22.50	23.70	25.07	26.64	28.48	30.67	33.35	36.77
	140	27.04	27.70	28.40	29.14	30.78	32.65	34.83	37.40	40.54	44.47	49.69	
	160	35.74	36.74	37.80	38.95	41.52	44.56	48.24	52.88	58.99			
	180	47.39	48.99	50.74	52.66	57.14	62.84	70.51					
50	70	4.43	4.52	4.61	4.70	4.90	5.12	5.37	5.64	5.94	6.29	6.69	7.15
	90	9.33	9.52	9.72	9.93	10.38	10.87	11.43	12.05	12.76	13.58	14.55	15.70
	110	14.85	15.17	15.51	15.87	16.64	17.51	18.49	19.61	20.91	22.45	24.31	26.63
	130	21.26	21.76	22.29	22.85	24.09	25.49	27.10	28.99	31.25	34.03	37.59	42.42
	150	28.99	29.76	30.58	31.45	33.39	35.66	38.35	41.64	45.80	51.37		
	170	38.90	40.11	41.41	42.85	46.05	50.00	55.01	61.73				
	190	52.95	55.05	57.38	60.01	66.43	75.33						
60	80	4.65	4.74	4.84	4.94	5.16	5.41	5.68	5.99	6.34	6.74	7.21	7.77
	100	9.82	10.03	10.25	10.49	10.99	11.55	12.19	12.91	13.74	14.72	15.90	17.35
	120	15.73	16.10	16.48	16.89	17.77	18.78	19.92	21.25	22.83	24.74	27.14	30.29
	140	22.72	23.30	23.91	24.56	26.01	27.68	29.64	31.98	34.88	38.62	43.73	
	160	31.36	32.28	33.25	34.31	36.68	39.52	43.00	47.45	53.48			
	180	42.92	44.43	46.09	47.91	52.20	57.72	65.28					
	200	60.75	63.74	67.19	71.23	82.09							
170	175	2.91	3.06	3.24	3.44	3.99	4.85	6.71					
	180	6.09	6.43	6.82	7.29	8.54	10.66	16.10					
	185	9.60	10.17	10.84	11.64	13.86	17.92						
	190	13.64	14.41	15.43	16.68	20.29	27.80						
	210	37.30	41.17	46.43	54.33								
	230												
180	185	3.51	3.74	4.02	4.36	5.34	7.47						
	190	7.45	7.97	8.61	9.40	11.83	18.24						
	195	11.93	12.84	13.96	15.40	20.17							
	200	17.13	18.58	20.42	22.86	32.04							
	220	57.44	70.53										
	240												
190	195	4.47	4.86	5.36	6.01	8.55							
	200	9.67	10.60	11.82	13.51	21.42							
	205	15.89	17.63	19.99	23.52								
	210	23.67	26.72	31.19	38.90								
	230												
	250												

Figure 15. Facility Heat Exchanger Performance Chart [4:17]

Table XI

Fuel Cell Heat Exchanger GPM Output Requirement

Facility	Fuel Cell Output	Facility Heat Exchanger Supply & Return Water Temperatures
MFH Unit Cluster	26,250 BTU/hr	230 to 150°F
Bldg. 641	105,000 BTU/hr	230 to 190°F
Bldg. 485	352,500 BTU/hr	230 to 200°F

. . . . Table XI (Continued) . . . .

Facility Water Temperature Rise Requirement	BTU Factor	Required GPM
52 to 140°F	8.33	0.7
170 to 190°F	8.10	5.4
180 to 200°F	8.06	24.3

With the required gpm flow calculated, the next step was to match the gpm flow to the fuel cell heat exchanger performance data. This data was in the form of two graphs (Figures 17 and 18) developed from data obtained from an operational 40 KW fuel cell power plant manufactured by United Technologies Corporation.

The graph values were converted by a size ratio multiplier to obtain approximate gpm and thermal output values for each size fuel cell. For example, the graph gpm and BTU/hour values would be multiplied by 7KW/40 KW to obtain approximate heat exchanger output values for the 7 KW fuel cell power plant.

After comparing these heat exchanger performance graphs with the return water temperatures of 190°F and 200°F for Buildings 416 and 485, respectively, it became apparent that some means to reduce the return water temperature was required. Note, for example, that a return water temperature of 190°F is off the performance graphs of both the high and low heat exchangers.

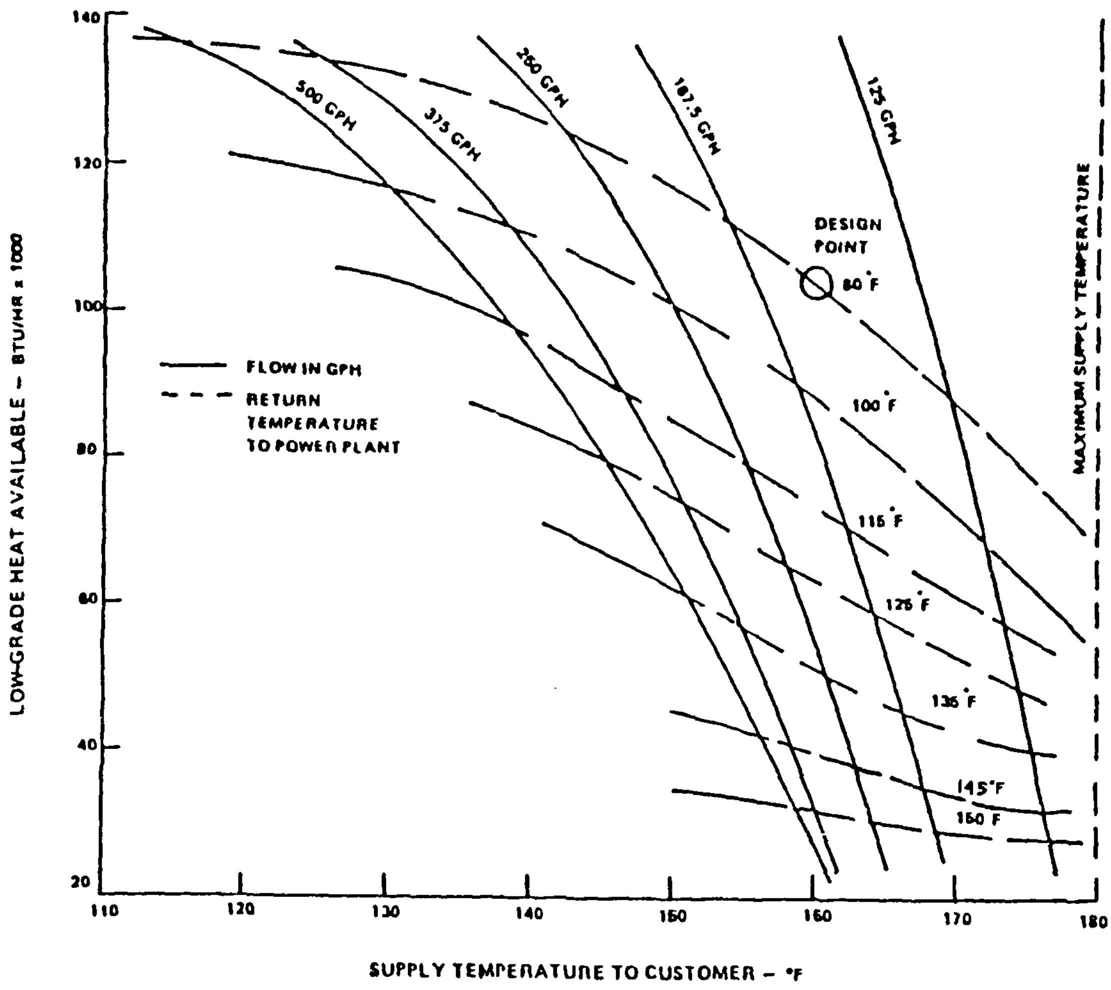


Figure 16. Low Grade Heat Exchanger Performance Graph [1:27]

In order to reduce the return water temperature, the author considered the addition of water-to-air heat exchangers in the return air ducts of the HVAC systems of these facilities. This option was not used due to the extensive facility HVAC modifications required, and also because the heat exchanger could not be used during the summer months when cooling air was required by the facility.

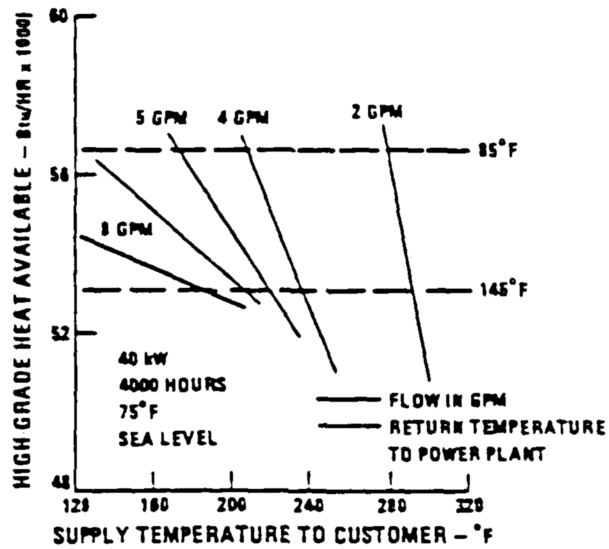


Figure 17. High Grade Heat Exchanger Performance Graph [20:424]

The approach chosen was to install a water-to-air heat exchanger at the fuel cell power plant site. The output of this heat exchanger would be modulated by a temperature controlled three-way valve such that 145 °F return water would be made available to the high grade heat exchanger year round. The return water temperature was kept as high as practical to limit the thermal energy loss to the atmosphere.

Using the same formula stated at the beginning of this appendix, the size of the water-to-air heat exchangers were estimated to be 68,000 BTU/hour for Building 641 and 283,000 BTU/hour for Building 485. An additional heat exchanger was not required for the MFH unit cluster system because the

return water temperature of 150°F would drop approximately 5°F traveling through the relatively long return water piping system.

The actual gpm and temperature values taken from the heat exchanger graphs are listed in Table XII. Also listed is the amount and percentage of fuel cell generated thermal energy able to be transferred to the heating system of each facility.

Table XII

Fuel Cell Thermal Energy Transferred to Facility

Facility	GPM	Temperature	Thermal Transfer	Percent
MFH Unit Cluster	0.73*	232°F	13,130 BTU/hr	50
Bldg. 641	3.10	230°F	37,100 BTU/hr	35
Bldg. 485	10.60	230°F	124,350 BTU/hr	35

* Combined output of high and low grade heat exchangers:
(290 °F X .35 gph) + (177 °F X .37 gph) = (232 °F X .73 gph)

Appendix E

Fuel Cell Power Plant Natural Gas Consumption

The natural gas consumption of the fuel cell power plant was calculated based on a gas to electricity conversion efficiency of 40 percent [6:265]. The author also used Wakefield's estimate of operational reliability of 97 percent (i.e., 354 days per year) [22:H-3]. Table XIII lists the annual consumption values, determined by the formula below, for each facility.

$$\frac{\text{Fuel Cell KW} \times 24\ \text{hr/day} \times 354\ \text{days/yr}}{0.4\ \text{efficiency}} \times 3413\ \text{BTU/KW}$$

$$\times \frac{1}{1031\ \text{BTU/cu ft of gas}} = \text{Cubic Feet of Natural Gas Consumed per Year}$$

Table XIII lists the annual consumption values for each facility.

Table XIII

Annual Fuel Cell Power Plant Natural Gas Consumption

Facility	Annual Gas Consumption(cu ft)
MFH Unit Cluster	485,859
Building 641	1,968,748
Building 485	6,609,369

The capacities of the existing natural gas distribution systems at all three facility locations were found to be adequate to handle the additional load of the fuel cell installations. The increase in gas consumption, assuming a conservative estimate of no reduction in existing consumption, was less than one percent for the MFH unit clusters and Building 485. For Building 641, an abandoned three inch gas line to the facility would easily handle the fuel cell power plant gas requirement.

Appendix F

Sample Cost Escalation Calculation

The first fuel cell power plant installed cost shown in Table III is \$1509/KW. The original cost, \$1203/KW, was obtained from Bollenbacher's study and was estimated in 1981 dollars [5:Table V]. To convert to 1986 dollars for the life-cycle cost analysis, historical cost indices from [14] were used as follows:

$$\underset{\text{(1986 Dollars)}}{\text{Present Cost}} = \text{Previous Cost(1981 Dollars)} \times \frac{\text{July 1985 Index}}{\text{July 1981 Index}}$$

$$\times\ 1.063 \text{(Est. 6.3\% Annual Inflation 1985 to 1986) [14:406]}$$

Substituting Actual Data:

$$\underset{\text{(1986 Dollars)}}{\text{Present Cost}} = \$1203/\text{KW} \times \frac{189.1}{160.2} \times 1.063 = \$1509/\text{KW}$$

This method was also used to convert O&M costs to 1986 dollars

Appendix G

Life-Cycle Cost Analysis and Summary

The unit costs for energy and the annual energy savings and consumption were calculated as shown in Table XIV. These values were used in Part 2 of the Life-Cycle Cost Summary.

Table XIV

Energy Unit Cost and Annual Savings/Consumption Calculations

1986 Energy Unit Cost per Million BTU (MBTU)

Fuel

Elec $\frac{\$0.0485/\text{KWH}\ *}{11.6\ \text{KBTU/KWH}} \times 1000\text{KBTU/MBTU} = \$4.18/\text{MBTU}$

Gas $\frac{\$5.23/1000\ \text{cu ft}\ *}{1.031\ \text{MBTU}/1000\ \text{cu ft}} = \$5.07/\text{MBTU}$

Steam .... $4.91/MBTU *

* From 2750th/DEEU

. . . .

Annual Energy Savings - Gas or Steam

Facility

MFH Unit Cluster $\frac{13{,}130\ \text{BTU/hr}\ ** \times 8496\ \text{hr/yr}}{1{,}000{,}000\ \text{BTU/MBTU}} =$ 112 MBTU/yr (Gas)

Bldg. 416 $\frac{37{,}100\ \text{BTU/hr}\ ** \times\ \text{"}}{\text{"}} =$ 315 MBTU/yr (Steam)

Bldg. 485 $\frac{124{,}350\ \text{BTU/hr}\ ** \times\ \text{"}}{\text{"}} =$ 1057 MBTU/yr (Gas)

** From Table IV

. . . .

. . . . Table XIV (Continued) . . . .

Annual Energy Savings - Electricity

MFH Unit Cluster	7 KW	X	8496 hr/yr	X	Ø.Ø166 MBTU/KWH	=	69Ø	MBTU/yr
Bldg. 641	28 KW	X	"	X	"	=	2759	MBTU/yr
Bldg. 485	94 KW	X	"	X	"	=	9264	MBTU/yr

. . . .

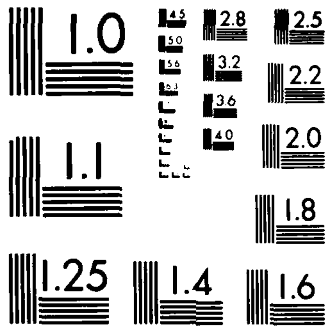
Annual Energy Consumption - Natural Gas

MFH Unit Cluster	485,859 cu ft	X	.ØØ1Ø31 MBTU/cu ft	=	5Ø1	MBTU/yr
Bldg. 641	1,968,748 cu ft	X	"	=	2Ø3Ø	MBTU/yr
Bldg. 485	6,6Ø9,369 cu ft	X	"	=	6814	MBTU/yr

Cu ft consumption values from Table XIII

AD-A175 124 ECONOMIC FEASIBILITY OF FUEL CELL ENERGY SYSTEMS FOR SELECTED FACILITIES O..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. S A BIRD 2/2

UNCLASSIFIED SEP 86 AFIT/GEM/LSM/86S-2 F/G 10/2 NL


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

LIFE-CYCLE COST ANALYSIS SUMMARY

(Attachment 1 to ETL 82-4)

General

The Life-Cycle Cost Analysis Summary is to be used for determining Savings to Investment Ratios (SIR) for complete ECIP projects and for discrete portions of projects. In using this form, the cost of construction; supervision; inspection and overhead (SIOH); design costs, salvage value; unit costs of energy and recurring and nonrecurring non-energy costs are determined as of the date the analysis is made.

Title Block

Identify project title and if applicable, the discrete portion of the project being analyzed. The installation region is determined by its location (see Table XV).

Line 1 Investment Costs

All investment costs are determined as of the date the analysis is made. For determining SIR for energy conservation retrofits the total of the construction, SIOH and design costs must be reduced to 90 percent of the original estimated cost. Salvage value is the residual value of existing equipment removed as a result of the retrofit project. Investment costs do not include energy audit costs, preliminary design, not analysis costs since these efforts are required by Executive Order, legislation, or DoD requirements and are therefore considered sunk costs.

Line 2 Energy Savings

By definition ECIP projects must save energy, therefore there will always be an overall energy cost savings. The overall savings may include increases in use of one fuel and a decrease in use of another. For each fuel, attach computations to show and substantiate the energy savings (2.) claimed. Use conservation factors to convert to MBTUs. The cost per MBTU (1) is the cost of energy at the installation on the date of the analysis. Care must be taken to use the same conversion factors used in (1) to develop the appropriate unit cost, eg. electric cost of $50/mwh = $4.31/MBTU, using 11.6 MBTU/mwh. The annual savings is the product of (1) x (2). The discount (UPW) factors (4) are obtained from Table XV.

The discounted savings (5) are determined by multiplying (3) x (4).

Line 3 Non-Energy Savings

Annual recurring savings/costs will include items such as electrical demand savings, operator/maintenance savings (labor and material).

For annually recurring savings/costs obtain the discount (UPW) factor from Table XVI Section 3D calculations assures project qualification based on the criteria requirement that 75 percent of the discounted cost savings must be derived directly from energy (MBTU) savings. [Maximum allowable non-energy savings equals discounted energy savings divided by .75 multiplied by .25, -i.e., (1 ÷ .75 x .25 = .33 factor.)] If applicable, the retrofit will qualify for inclusion in the program only if (SIR) line 3D1b is equal to or greater than 1.

Line 4

First year dollar savings equals 2F3 + 3A (3B1d ÷ years economic life). *NOTE: First year dollar savings is defined as the summation of the first year energy and non-energy savings plus the total nonrecurring, non-energy savings divided by the economic life of the retrofit action.*

Line 5

Total net discounted savings equals 2F5 + 3C.

Line 6

Project qualifies for inclusion in the program, if not previously disqualified in Test 3D, and SIR on Line 6 is equal to or greater than 1.

Energy Conversion Factors

a. For purpose of calculating energy savings, the following conversion factors will be used:

Purchased Electric Power	11,600 BTU/kwh
Distillate Fuel Oil	138,700 BTU/gal
Residual Fuel Oil	149,690 BTU/gal
Natual Gas	1,031,000 BTU/1000 cu. ft.
LPG, Propane, Butane	95,000 BTU/gal
Bituminous Coal	24,580,000 BTU/Short Ton
Anthracite Coal	25,400,000 BTU/Short Ton
Purchased Steam	1,340 BTU/lb

The conversion factors for fossil fuels should be used only if actual fuel BTU content is not known. If known, actual values should be used.

b. Purchased energy is defined as being generated off-site. For special cases where electric power or steam is obtained from on-site sources, the actual average gross energy input to the generating plant will be used.

c. The term "coal" does not include lignite. Where lignite is involved, the Bureau of Mines average value for the source field shall be used.

d. Where refuse derived fuel (RDF) is involved, the heat value shall be the average of the RDF being used or proposed or 6,000,000 BTU/Short Ton if not known.

TABLE XV UPW* DISCOUNT FACTORS ADJUSTED FOR AVERAGE FUEL PRICE ESCALATION
BY END-USE SECTOR AND MAJOR FUEL
DISCOUNT RATE = 7 PERCENT
DoE Region 5 (Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio)

	RESIDENTIAL				COMMERCIAL					INDUSTRIAL					TRANSPORTATION	
SP	ELEC	DIST	LPG	NATGAS	ELEC	DIST	RESID	NATGAS	COAL	ELEC	DIST	RESID	NATGAS	COAL	GASLNE	SP
1	0.96	0.91	0.92	0.94	0.96	0.91	0.93	0.94	0.95	0.96	0.91	0.93	0.93	0.94	0.91	1
2	1.87	1.77	1.77	1.84	1.87	1.76	1.81	1.83	1.84	1.88	1.77	1.82	1.82	1.84	1.77	2
3	2.71	2.60	2.60	2.71	2.71	2.59	2.66	2.69	2.68	2.72	2.59	2.68	2.69	2.68	2.58	3
4	3.47	3.39	3.39	3.55	3.47	3.39	3.47	3.54	3.48	3.49	3.39	3.53	3.53	3.48	3.36	4
5	4.17	4.16	4.16	4.39	4.17	4.17	4.25	4.37	4.24	4.18	4.17	4.37	4.37	4.23	4.10	5
6	4.80	4.92	4.91	5.21	4.80	4.94	5.01	5.20	4.96	4.81	4.93	5.20	5.20	4.95	4.82	6
7	5.39	5.66	5.65	6.03	5.39	5.71	5.74	6.02	5.64	5.39	5.69	6.02	6.04	5.62	5.52	7
8	5.93	6.38	6.38	6.84	5.92	6.46	6.45	6.83	6.29	5.92	6.43	6.83	6.86	6.26	6.21	8
9	6.42	7.09	7.08	7.65	6.42	7.20	7.13	7.64	6.89	6.40	7.16	7.62	7.68	6.87	6.87	9
10	6.87	7.78	7.78	8.43	6.87	7.93	7.79	8.44	7.47	6.85	7.87	8.40	8.48	7.43	7.51	10
11	7.31	8.46	8.45	9.20	7.30	8.64	8.44	9.21	8.01	7.27	8.57	9.15	9.27	7.97	8.13	11
12	7.72	9.11	9.08	9.94	7.71	9.32	9.06	9.96	8.53	7.67	9.25	9.88	10.04	8.48	8.72	12
13	8.10	9.74	9.72	10.66	8.10	9.99	9.67	10.69	9.02	8.05	9.92	10.60	10.80	8.96	9.29	13
14	8.47	10.35	10.33	11.36	8.46	10.64	10.26	11.40	9.48	8.42	10.57	11.29	11.54	9.42	9.83	14
15	8.82	10.94	10.92	12.04	8.81	11.27	10.84	12.10	9.91	8.76	11.20	11.96	12.27	9.85	10.36	15
16	9.14	11.51	11.49	12.69	9.14	11.88	11.40	12.77	10.33	9.09	11.82	12.61	12.97	10.26	10.86	16
17	9.45	12.06	12.04	13.33	9.45	12.45	11.94	13.42	10.71	9.39	12.41	13.24	13.66	10.64	11.33	17
18	9.74	12.59	12.57	13.94	9.74	13.03	12.46	14.05	11.08	9.68	12.99	13.85	14.33	11.01	11.79	18
19	10.01	13.10	13.07	14.53	10.01	13.58	12.96	14.65	11.42	9.95	13.55	14.43	14.98	11.35	12.22	19
20	10.27	13.59	13.56	15.11	10.27	14.10	13.43	15.24	11.75	10.21	14.09	15.00	15.61	11.67	12.64	20
21	10.51	14.07	14.04	15.66	10.51	14.61	13.92	15.81	12.05	10.45	14.61	15.55	16.23	11.97	13.04	21
22	10.73	14.53	14.50	16.20	10.73	15.11	14.38	16.37	12.34	10.68	15.13	16.08	16.83	12.25	13.43	22
23	10.94	14.98	14.94	16.72	10.94	15.59	14.83	16.91	12.61	10.89	15.63	16.60	17.42	12.52	13.80	23
24	11.14	15.42	15.37	17.22	11.13	16.06	15.27	17.43	12.86	11.08	16.12	17.10	17.99	12.77	14.15	24
25	11.32	15.84	15.79	17.71	11.31	16.52	15.69	17.93	13.10	11.26	16.59	17.59	18.54	13.01	14.50	25

Table XVI UPW Factors for Finding the Present Value of Future Nonfuel Annually Recurring Amounts[1]

Study Period (Years)	UPW Factor (d=.07)	UPW Factor (d=.10)
1	0.93	0.91
2	1.81	1.74
3	2.62	2.49
4	3.39	3.17
5	4.10	3.79
6	4.77	4.36
7	5.39	4.87
8	5.97	5.33
9	6.52	5.76
10	7.02	6.14
11	7.50	6.50
12	7.94	6.81
13	8.36	7.10
14	8.75	7.37
15	9.11	7.61
16	9.45	7.82
17	9.76	8.02
18	10.06	8.20
19	10.34	8.36
20	10.59	8.51
21	10.84	8.65
22	11.06	8.77
23	11.27	8.88
24	11.47	8.98
25	11.65	9.08

[1]The formula for finding the present value (P) of an annually recurring uniform amount (A) is the following:

$$P = A \cdot \frac{(1+d)^n - 1}{d(1+d)^n} = A \cdot \text{UPW Factor},$$

where d = the discount rate; and
n = the number of years over which A occurs.

LIFE-CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Wright-Patterson AFB, OH REGION NO. 5 PROJECT NUMBER ______

PROJECT TITLE MFH Unit Cluster Fuel Cell Energy System FISCAL YEAR 86

DISCRETE PORTION NAME ______

ANALYSIS DATE Aug 86 ECONOMIC LIFE 25 YEARS PREPARED BY S. Bird

1. INVESTMENT
   A. CONSTRUCTION COST (Pwr Plant & Elec/Therm Interface) $ 17,120
   B. SIOH * $ ---
   C. DESIGN COST * $ ---
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ 15,551
   E. SALVAGE VALUE OF EXISTING EQUIPMENT (0%) -$ 0
   F. TOTAL INVESTMENT (1D-1E) $ 15,551
   * Included in Construction Cost

2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELEC	$ 4.18	690	$ 2,884	11.26	$ 32,474
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$ 5.07	-389	$ -1,972	18.54	$ -36,561
E. COAL	$		$		$
F. TOTAL		301	$ 912		-4,087 → $ -4,087

3. NON ENERGY SAVINGS (+) / COST (-)
   A. ANNUAL RECURRING (+/-) $ -952
      (1) DISCOUNT FACTOR (TABLE A) 11.65
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -11,091

   B. NON RECURRING SAVINGS (+) / COST (-): Included in Annual Recurring Cost

ITEM	SAVINGS (+) COST (-)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS (+) COST (-)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$ ---			$ ---

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS (+) / COST (-) (3A2+3Bd4) $ -11,091

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ N/A
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1) ÷ 1F = ______
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. FIRST YEAR DOLLAR SAVINGS 2F3+3A+(3B1d ÷ YEARS ECONOMIC LIFE) $ -40

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ -15,178

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR) = (5 ÷ 1F) = -.98

LIFE-CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Wright-Patterson AFB, OH REGION NO. 5 PROJECT NUMBER ______

PROJECT TITLE MFH Unit Cluster Fuel Cell Energy System FISCAL YEAR 86

DISCRETE PORTION NAME ______

ANALYSIS DATE Aug 86 ECONOMIC LIFE 25 YEARS PREPARED BY S. Ford

1. INVESTMENT
   A. CONSTRUCTION COST (Pwr Plant & Elec/Therm Interface) $ 20,9[illegible]
   B. SIOH * $ ---
   C. DESIGN COST * $ ---
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ 18,87[illegible]
   E. SALVAGE VALUE OF EXISTING EQUIPMENT (0%) -$ 0
   F. TOTAL INVESTMENT (1D-1E) $ 18,871
   * Included in Construction Cost

2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELEC	$ 4.18	690	$ 2,884	11.26	$ 32,474
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$ 5.07	-389	$ -1,972	18.5[illegible]	$ -36,561
E. COAL	$		$		$
F. TOTAL		301	$ 9[illegible]		-4,087 → $ -4,087

3. NON ENERGY SAVINGS (+) / COST (-)
   A. ANNUAL RECURRING (+/-) $ -1,356
      (1) DISCOUNT FACTOR (TABLE A) 11.65
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -15,797

   B. NON RECURRING SAVINGS (+) / COST (-): Included in Annual Recurring Cost

ITEM	SAVINGS (+) COST (-)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(-)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$ ---			$ ---

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS (+) / COST (-) (3A2+3Bd4) $ -15,797

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ N/A
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F= ______
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. FIRST YEAR DOLLAR SAVINGS 2F3+3A+(3Bld ÷ YEARS ECONOMIC LIFE) $ -444

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ -19,884

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR)=(5÷1F)= -1.05

LIFE-CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Wright-Patterson AFB, OH REGION NO. 5 PROJECT NUMBER ______

PROJECT TITLE MFH Unit Cluster Fuel Cell Energy System FISCAL YEAR 86

DISCRETE PORTION NAME ______

ANALYSIS DATE Aug 86 ECONOMIC LIFE 25 YEARS PREPARED BY S. Bird

1. INVESTMENT
   A. CONSTRUCTION COST (Pwr Plant & Elec/Therm Interface) $ 22,102
   B. SIOH * $ ---
   C. DESIGN COST * $ ---
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ 19,892
   E. SALVAGE VALUE OF EXISTING EQUIPMENT (0%) -$ 0
   F. TOTAL INVESTMENT (1D-1E) $ 19,892
   * Included in Construction Cost
2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELEC	$ 4.18	690	$ 2,884	11.26	$ 32,474
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$ 5.0	-389	$ -1,972	18.54	$-36,561
E. COAL	$		$		$
F. TOTAL		301	$ 912		-4,087 → $-4,087

3. NON ENERGY SAVINGS(+) / COST(-)
   A. ANNUAL RECURRING (+/-) $ -1,000
      (1) DISCOUNT FACTOR (TABLE A) 11.65
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -11,650

   B. NON RECURRING SAVINGS(+) / COST(-): Included in Annual Recurring Cost

ITEM	SAVINGS(+) COST (-)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(-)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$ ---			$ ---

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(-) (3A2+3Bd4) $-11,650

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ N/A
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F= ______
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. FIRST YEAR DOLLAR SAVINGS 2F3+3A+(3B1d ÷ YEARS ECONOMIC LIFE) $ -88

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $-15,737

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR)=(5÷1F)= -.79

LIFE-CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Wright-Patterson AFB, OH REGION NO. 5 PROJECT NUMBER ______

PROJECT TITLE Building 641 Fuel Cell Energy System FISCAL YEAR 86

DISCRETE PORTION NAME ______

ANALYSIS DATE Aug 86 ECONOMIC LIFE 25 YEARS PREPARED BY S. Bird

1. INVESTMENT
   A. CONSTRUCTION COST (Pwr Plant & Elec/Therm Interface) $ 49,284
   B. SIOH * $ ---
   C. DESIGN COST * $ ---
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ 44,356
   E. SALVAGE VALUE OF EXISTING EQUIPMENT (0%) -$ 0
   F. TOTAL INVESTMENT (1D-1E) $ 44,356
   * Included in Construction Cost

2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELEC	$ 4.18	2,759	$ 11,533	11.26	$ 129,857
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$ [illegible]	-2,030	$ -10,297	18.54	$ -190,814
E. COAL**	$ [illegible]	315	$ 1,547	13.03	$ 20,126
** Steam Plant Fuel					
F. TOTAL		1,044	$ 2,783		-40,831 → $ -40,831

3. NON ENERGY SAVINGS(+) / COST(-)
   A. ANNUAL RECURRING (+/-) $ -3,322
      (1) DISCOUNT FACTOR (TABLE A) 11.65
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -38,701

   B. NON RECURRING SAVINGS(+) / COST(-): Included in Annual Recurring Cost

ITEM	SAVINGS(+) COST (-)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(-)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$ ---			$ ---

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(-) (3A2+3Bd4) $ -38,701

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ N/A
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F= ______
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. FIRST YEAR DOLLAR SAVINGS 2F3+3A+(3B1d ÷ YEARS ECONOMIC LIFE) $ -539

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ -79,532

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR)=(5÷1F)= -1.79

LIFE-CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Wright-Patterson AFB, OH REGION NO. 5 PROJECT NUMBER ________

PROJECT TITLE Building 641 Fuel Cell Energy System FISCAL YEAR 86

DISCRETE PORTION NAME ________

ANALYSIS DATE Aug 86 ECONOMIC LIFE 25 YEARS PREPARED BY S. Bird

1. INVESTMENT
   A. CONSTRUCTION COST (Pwr Plant & Elec/Therm Interface) $ 44,748
   B. SIOH * $ ---
   C. DESIGN COST * $ ---
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ 40,273
   E. SALVAGE VALUE OF EXISTING EQUIPMENT (0%) -$ 0
   F. TOTAL INVESTMENT (1D-1E) $ 40,273
   * Included in Construction Cost
2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELEC	$ 4.18	2,759	$ 11,533	11.26	$ 129,857
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$ 5.0[illegible]	-2,030	$ -10,297	18.54	$ -190,8[illegible]
E. COAL**	$ 4.91	315	$ 1,547	13.01	$ 20,126
** Steam Plant Fuel					
F. TOTAL		1,044	$ 2,783		-40,831 → $ -40,831

3. NON ENERGY SAVINGS (+) / COST (-)
   A. ANNUAL RECURRING (+/-) $ -5,425
      (1) DISCOUNT FACTOR (TABLE A) 11.65
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -63,201

   B. NON RECURRING SAVINGS (+) / COST (-): Included in Annual Recurring Cost

ITEM	SAVINGS(+) COST (-)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(-)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$ ---			$ ---

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS (+) / COST (-) (3A2+3Bd4) $ -63,201

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ N/A
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1) ÷ 1F = ________
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. FIRST YEAR DOLLAR SAVINGS 2F3+3A+(3B1d ÷ YEARS ECONOMIC LIFE) $ -2,6[illegible]

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ -104,03[illegible]

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR) = (5 ÷ 1F) = -2.58

LIFE-CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Wright-Patterson AFB, OH   REGION NO. 5   PROJECT NUMBER ________

PROJECT TITLE Building 641 Fuel Cell Energy System   FISCAL YEAR 86

DISCRETE PORTION NAME ________

ANALYSIS DATE Aug 86   ECONOMIC LIFE 25 YEARS   PREPARED BY S. Bird

1. INVESTMENT
   A. CONSTRUCTION COST (Pwr. Plant & Elec/Therm Interface) $ 30,122
   B. SIOH * $ ---
   C. DESIGN COST * $ ---
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ 27,110
   E. SALVAGE VALUE OF EXISTING EQUIPMENT (0%) -$ 0
   F. TOTAL INVESTMENT (1D-1E) $ 27,110
      * Included in Construction Cost
2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELEC	$ 4.18	2,759	$ 11,533	11.26	$ 129,857
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$ 5.07	-2,030	$ -10,297	18.54	$ -190,914
E. COAL**	$ 4.91	315	$ 1,547	13.01	$ 20,126
** Steam Plant Fuel					
F. TOTAL		1,044	$ 2,783		-40,831 → $ -40,831

3. NON ENERGY SAVINGS(+) / COST(-)
   A. ANNUAL RECURRING (+/-) $ -3,806
      (1) DISCOUNT FACTOR (TABLE A) 11.65
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -44,340

   B. NON RECURRING SAVINGS(+) / COST(-): Included in Annual Recurring Cost

ITEM	SAVINGS(+) COST (-)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(-)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$ ---			$ ---

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(-) (3A2+3Bd4) $-44,340

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ N/A
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F= ________
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. FIRST YEAR DOLLAR SAVINGS 2F3+3A+(3B1d ÷ YEARS ECONOMIC LIFE) $ -1,023

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $-85,171

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR)=(5÷1F)= -3.14

LIFE-CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Wright-Patterson AFB, OH REGION NO. 5 PROJECT NUMBER ________

PROJECT TITLE Building 485 Fuel Cell Energy System FISCAL YEAR 86

DISCRETE PORTION NAME ________

ANALYSIS DATE Aug 86 ECONOMIC LIFE 25 YEARS PREPARED BY S. Bird

1. INVESTMENT
   A. CONSTRUCTION COST (Pwr Plant & Elec/Therm Interface) $ 139,968
   B. SIOH * $ ---
   C. DESIGN COST * $ ---
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ 125,971
   E. SALVAGE VALUE OF EXISTING EQUIPMENT (0%) -$ 0
   F. TOTAL INVESTMENT (1D-1E) $ 125,971
      * Included in Construction Cost

2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELEC	$ 4.18	9,264	$ 38,724	11.26	$ 436,032
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$ 5.07	-5,757	$ -29,188	18.54	$ -541,146
E. COAL	$		$		$
F. TOTAL		3,507	$ 9,536		-105,114 > $ -105,114

3. NON ENERGY SAVINGS (+) / COST (-)
   A. ANNUAL RECURRING (+/-) $ -18,182
      (1) DISCOUNT FACTOR (TABLE A) 11.65
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -211,820

   B. NON RECURRING SAVINGS (+) / COST (-): Included in Annual Recurring Cost

ITEM	SAVINGS (+) COST (-)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(-)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$ ---			$ ---

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS (+) / COST (-) (3A2+3Bd4) $ -211,820

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ N/A
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F= ________
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. FIRST YEAR DOLLAR SAVINGS 2F3+3A+(3Bd1÷YEARS ECONOMIC LIFE) $ -8,646

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ -316,934

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR)=(5÷1F)= -2.52

LIFE-CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Wright-Patterson AFB, OH REGION NO. 5 PROJECT NUMBER ______

PROJECT TITLE Building 485 Fuel Cell Energy System FISCAL YEAR 86

DISCRETE PORTION NAME ______

ANALYSIS DATE Aug 86 ECONOMIC LIFE 25 YEARS PREPARED BY S. Bird

1. INVESTMENT
   A. CONSTRUCTION COST (Pwr Plant & Elec/Therm Interface) $ 155,196
   B. SIOH * $ ---
   C. DESIGN COST * $ ---
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ 139,676
   E. SALVAGE VALUE OF EXISTING EQUIPMENT (C%) -$ 0
   F. TOTAL INVESTMENT (1D-1E) $ 139,676
   * Included in Construction Cost
2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELEC	$ 4.18	9,264	$ 38,724	11.26	$ 436,032
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$ 5.07	-5,757	$ -29,188	18.54	$ -541,146
E. COAL	$		$		$
F. TOTAL		3,507	$ 9,536		-105,114 > $ -105,114

3. NON ENERGY SAVINGS(+) / COST(-)
   A. ANNUAL RECURRING (+/-) $ -10,966
      (1) DISCOUNT FACTOR (TABLE A) 11.65
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -127,754

   B. NON RECURRING SAVINGS(+) / COST(-): Included in Annual Recurring Cost

ITEM	SAVINGS(+) COST (-)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(-)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$ ---			$ ---

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(-) (3A2+3Bd4) $ -127,754

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ N/A
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F= ______
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. FIRST YEAR DOLLAR SAVINGS 2F3+3A+(3B1d ÷ YEARS ECONOMIC LIFE) $ -1,430

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ -232,868

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR)=(5÷1F)= -1.67

LIFE-CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Wright-Patterson AFB, OH REGION NO. 5 PROJECT NUMBER ________

PROJECT TITLE Building 485 Fuel Cell Energy System FISCAL YEAR 86

DISCRETE PORTION NAME ________________________________

ANALYSIS DATE Aug 86 ECONOMIC LIFE 25 YEARS PREPARED BY S. Bird

1. INVESTMENT
   A. CONSTRUCTION COST (Pwr. Plant & Elec/Therm. Interface) $ 90,430
   B. SIOH * $ ---
   C. DESIGN COST * $ ---
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ 81,387
   E. SALVAGE VALUE OF EXISTING EQUIPMENT (0%) -$ 0
   F. TOTAL INVESTMENT (1D-1E) $ 81,387
   * Included in Construction Cost
2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELEC	$ 4.18	9,264	$ 38,724	11.26	$ 436,032
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$ 5.07	-5,757	$ -29,188	18.54	$ -541,146
E. COAL	$		$		$
F. TOTAL		3,507	$ 9,536		-105,114 > $ -105,114

3. NON ENERGY SAVINGS (+) / COST (-)
   A. ANNUAL RECURRING (+/-) $ -12,778
      (1) DISCOUNT FACTOR (TABLE A) 11.65
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -148,864

   B. NON RECURRING SAVINGS (+) / COST (-): Included in Annual Recurring Cost

ITEM	SAVINGS (+) COST (-)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(-)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$ ---			$ ---

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS (+) / COST (-) (3A2+3Bd4) $ -148,864

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ N/A
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1) ÷ 1F= ______
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. FIRST YEAR DOLLAR SAVINGS 2F3+3A+(3B1d ÷ YEARS ECONOMIC LIFE) $ -3,242

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ -253,978

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR)=(5 ÷ 1F)= -3.12

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VITA

Captain Stephen A. Bird was born on 20 July 1947 in Phoenix, Arizona. He graduated from Flagstaff High School in 1965 and received a Bachelor of Science Degree in Electrical Engineering from Northern Arizona University in 1975. He received his commission in the USAF on 15 December 1976 after completing OTS at Lackland AFB, Texas. His last assignment prior to entering the School of Systems and Logistics, Air Force Institute of Technology, was at HQ USAFE Ramstein AB, Germany where he was a project manager under the deputy chief of staff, Engineering & Services.

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Thesis Chairman: Phillip E. Miller, Major, USAF
Instructor of Logistics Management

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This thesis developed life-cycle costs of retrofitting fuel cell powered energy systems into existing facilities on Wright-Patterson Air Force Base (WPAFB), Ohio. These life-cycle costs were compared with existing costs for providing facility via comercially supplied electricity and natural gas and/or base generated steam. Three facilities representative of the main facility types on WPAFB were examined: Military Family Housing (MFH), an office/classroom building, and an office/lab building. An analysis of the cost compairsons was performed to determine if fuel cell energy systems can be economically competitive with existing facility energy utilization systems. The results of this analysis are contained in Chapter IV.

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